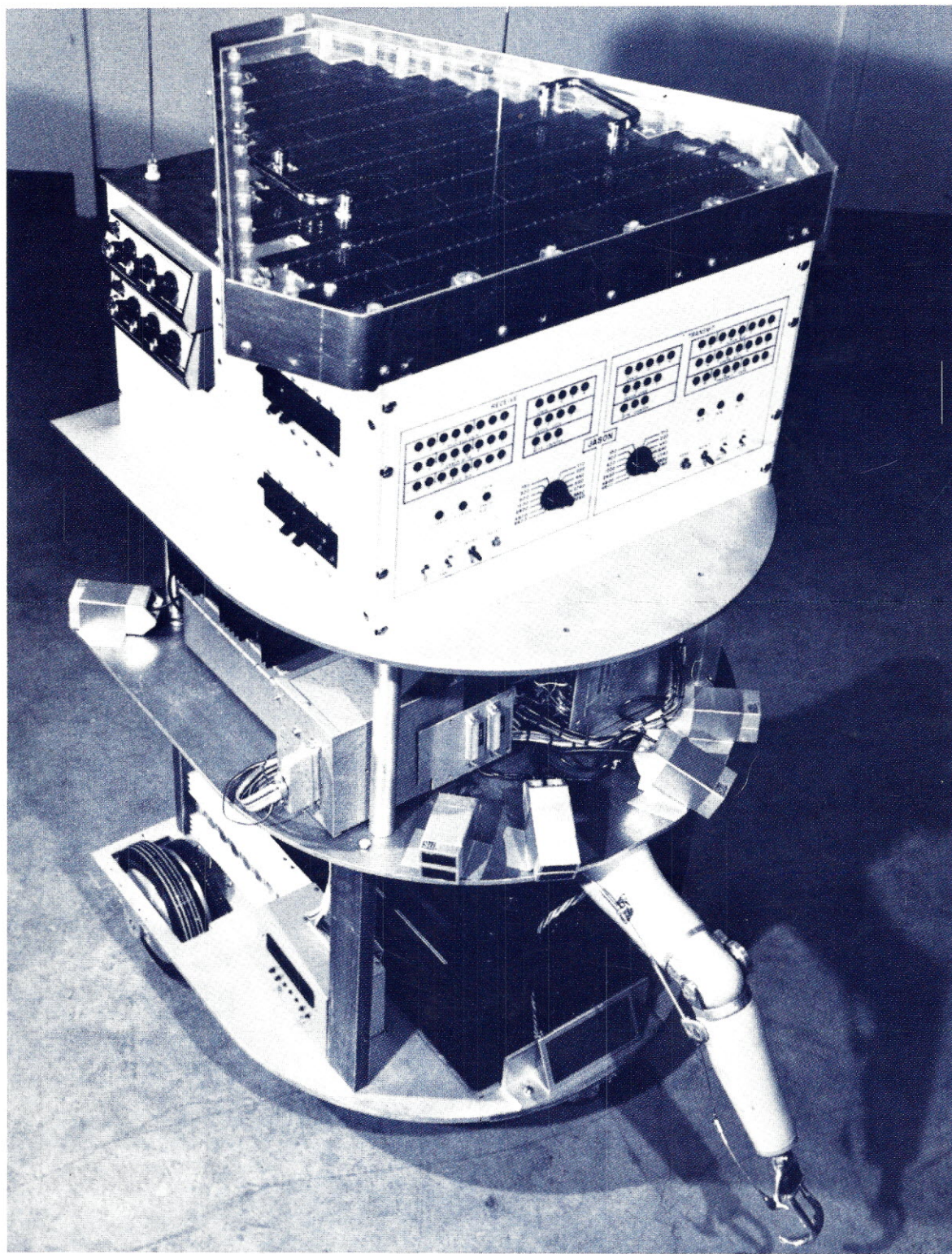


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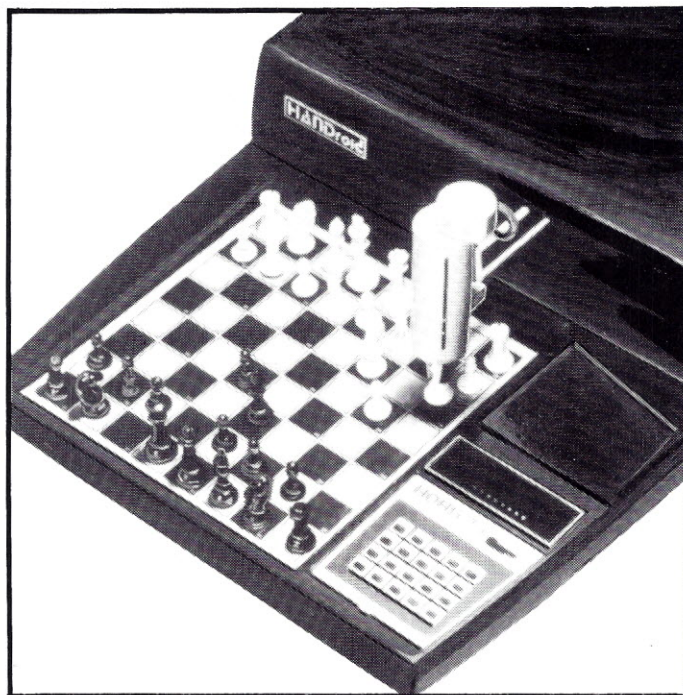
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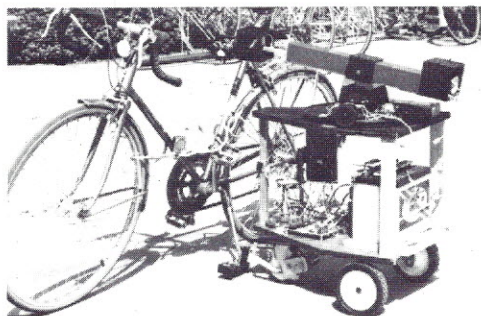
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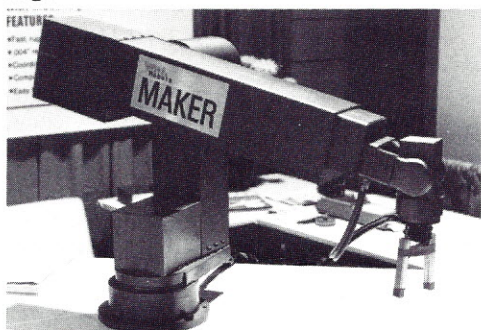
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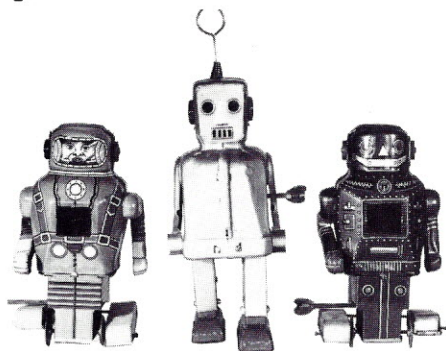
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# EDITORIAL

## *Robots and the Age of Intelligent Machines*

As **Robotics Age** begins a new year of publication, we thought it would be appropriate to elaborate a little on our new subtitle, *The Journal of Intelligent Machines*, which was added to our masthead last issue. Clearly, every reader has some idea of what the term "intelligent machine" means, and probably very few readers' images coincide, although there would surely be some elements common to all. Those similarities could be examined more closely to try to arrive at a "definition" of what is or is not an intelligent machine, but that is not really our goal. Instead, we find it more productive to look at the direction in which industrial robots are evolving and try to extrapolate just a little to see what the character of the field could be in just a few years.

As Victor Scheinman, inventor of the Unimate PUMA robot, said in his interview in **Robotics Age** (Fall 1980), the intrinsic positioning accuracy of today's robots is just about at a peak, with many machines now capable of returning to within .004" of a previously defined location. Even with this great precision, however, many of our efforts towards automated manufacturing still miss the point! We spend thousands of dollars, quite often equal to the price of the robot, on precision fixtures and parts feeders that place workpieces into "exact" locations so that the robot's pre-determined movements will accomplish the task. In far too many cases, this added expense prevents the application from being cost-effective.

This is where one trend in

intelligent robots is becoming increasingly important—the use of sophisticated sensors to allow the robot to compensate automatically for variations in the process. There are many elaborations on this theme: the use of vision systems for part acquisition and inspection, inductive sensors for edge or seam following, force-torque sensors for assembly tasks, etc.—the list gets longer every year.

Almost every advance in sensory processing technology makes new applications feasible, although fixturing cost savings are usually reduced by the extra cost of the sensory system, the end product is a much more flexible, intelligent machine that can be applied to other tasks much more readily. The investment is in a more general purpose tool, instead of a "dead" investment in custom fixturing.

One point to realize is that, although sensor design presents challenges in itself, the character of the industrial robot market is rapidly moving towards increased intelligence in the controller. As this happens, the nature of the problems, both in design and in application, is quickly changing from hardware to software. Even given a source of raw sensory data, such as a TV signal or the voltages across a set of strain gauges, that data must be processed into a form that will allow the robot controller to make a decision about what to do. Taking video image interpretation as an obvious example, this processing may become tremendously complex. Similarly, as we try to push our manipulators to the limits of their mechanical performance to attain the fastest movements for low part cycle times, the burden on the controller increases dramatically, as

it *must* take into account the effects of the arm's changing inertia as it moves and lifts payloads.

The impact of this swing from hardware to software doesn't stop with the robot manufacturer. Whereas the traditional industrial robot was programmed entirely by manual guide-through using a remote control box or direct contact, more manufacturers are now providing programming languages for describing the robot's task in a sequence of written commands. Again, this greatly increases the flexibility of the system by allowing the user to include logical tests and alternative actions, based on sensory inputs or signals from other equipment, or to redefine target locations under program control (as in palletizing or packaging).

Once more, although this new capability makes possible the automation of tasks heretofore infeasible, it does impose additional burdens on the application engineer, who must now add programming skills to his or her repertoire—the alternative being to add a computer professional to the application development staff, attracted from a labor pool that is growing increasingly more selective and highly paid.

What emerges is a realization that we are dealing with a problem common to all domains experiencing the rapid growth in computerization, be it administrative functions or the control of machines. We are forced by economic pressures to automate, but in so doing we must change, sometimes radically, the way we work and ultimately the way we live, though the latter is a different issue.

As we see it, the problem of robotics is much broader than

automatic control—the ultimate issue is that of *cognition*. Increased sensory capabilities are one aspect of this: designers attempt to give the robot a limited “understanding” of some facet of the task, as in the case of seam or edge following. Talents such as these are examples of “specialized” intelligence that apply to a limited number of applications.

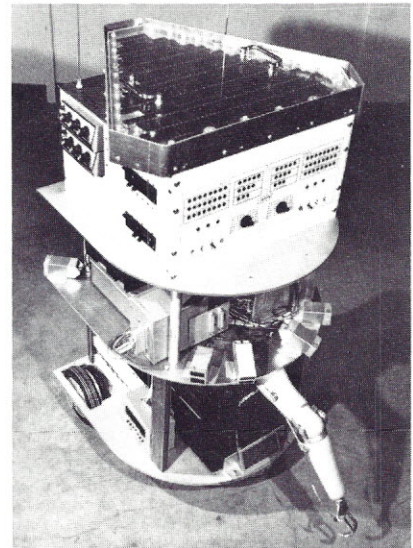
When it comes to the case of the robot programmed in software by the user, the solution to the application development issue is an extension of the same theme: more task-oriented intelligence in the controller, leading to a repertory of higher-level verbs that the machine understands. We already have an implicit “Follow” command in some specialized robots, but in software-programmed machines it should be possible for commands at this level to be given *explicitly*, allowing the programmer to say “Insert.” and, eventually, “Assemble.” This robustness must be supported by a human-engineered “friendly” development environment that will allow the user to define the geometric details of the task in a natural, interactive way.

For far too long has the task of program development been viewed as a skill to be practiced by the few. We now have the tools and the experience to avoid having the development of intelligent robots follow the unfortunate path of the data processing industry. A recent survey of top corporations, reported in the *Wall Street Journal*, stated that these firms averaged about *two years* behind in their software development. With proper attention to human-machine communication at the outset, this unfortunate track record need not be repeated as computers move into the factory.

New research points to even more exciting possibilities. It is now computationally feasible to have a development system perform a good deal of the detailed programming, based on information obtained from natural English-language interaction with the user. This, and other developments in Artificial Intelligence research, will lead to goal-oriented machines capable of task planning and self-programming of process steps. The geometric modelling systems under development at several centers are important prerequisites to this ability, as are the “knowledge representation” and automatic planning and deduction efforts being pursued at others.

Common to all of these approaches is the attempt to give the machine an understanding, expressed in a database model of the problem, of exactly what is to be accomplished. This shift from human pre-programming, with the computer blindly following instructions, to a machine with cognitive capabilities that collaborates with the user in the solution to the problem, is one of the themes of the Robotics Age and will be an essential ingredient in the intelligent machines of the future. With it, our efforts towards computer-aided design and manufacturing (CADAM), as well as the many other potentials of smart robots, will reach their fullest realization.

—Alan Thompson



### About the Cover

Pictured is JASON, a robot built by students in the EE Dept. at UC Berkeley. The robot is equipped with a number of infrared proximity sensors and a radio link to its remote computer controller. Its on-board microcomputer is responsible for data collection, communication, and simple control behavior, while its remote computer performs higher level calculations for navigation and planning. A prosthetic arm was mounted, but has not been interfaced to the robot.

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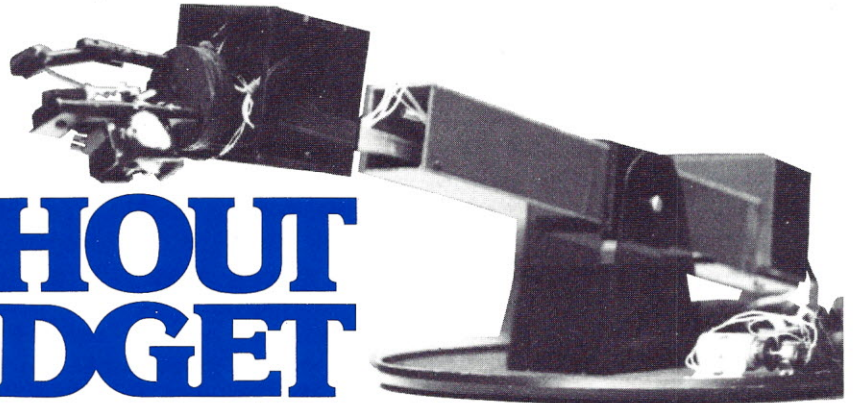
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# A ROBOT ARM WITHOUT A BUDGET

by  
Timothy Nagle  
and V. Michael Powers

Electrical & Computer Engineering Dept.  
Oregon State University  
Corvallis, OR 97331



## Introduction

A robot's not a robot in any of the fantasy or practical senses unless it can manipulate its environment. To us, a robot is little fun unless it can hand out mail, flip a switch, scare a friend, etc.

This article describes a portion of a robot project dedicated to building a low-cost manipulator; an arm, if you will, which can pick up and move light objects. The "Fanny Pincher" (FP) has fingers for grasping and a wrist and arm for positioning or carrying objects such as a glass of water or a soldering iron.

FP was built as part of a collection of projects underway by the Robot Group, a continuing group of Oregon State University students sponsored (but rarely funded) by the student IEEE chapter and the Electrical and Computer Engineering Department. Most of the current projects are spinoffs resulting from ideas which arose while contemplating the Micro-Mouse problem posed by the IEEE *Spectrum* magazine. Some students simultaneously complete the requirements of a credit-carrying project in EE, while others squeeze their participation into their schedules as an extracurricular activity.

The one project currently involving the most students is a three-wheeled cart named "Sparko." Sparko has one powered, steerable wheel and is capable of carrying a full-grown person. A single-chip microcomputer (Intel 8748) has been programmed to read light sensors and keep the

tricycle on track while it follows a trail consisting of an adding machine tape laid on the floor. While plans continue to add a single-board Z-80 computer for higher levels of coordination, feelers, and acoustic and optical sensing, the FP project was undertaken to provide an arm mounted on top of the vehicle that could swing around and up and down and do whatever seemed useful, amusing, or most importantly, challenging. (Figures 1 & 2)

No budget is given, not because cost was unimportant but because it was paramount. Many of the materials and items used were scrap; other choices and other mechanisms might have been implemented from a different scrap pile. Nonetheless, the methods reported here work, and others may find them or variations thereon useful in their own work.

## The Arm's Degrees of Freedom

An arm is a movable appendage. In the world of manipulators, an arm is categorized first in terms of the *degrees of freedom*, or the number of different ways it can move, and then, further, in terms of which kinds and how far each different movement is. In that sense, the FP arm has four degrees of freedom: limited rotation on top of the tricycle (side to side), extension of 30 cm., elevation of +15 to -22 degrees and wrist rotation of three turns around the longitudinal axis of the arm. Respectively, these motions

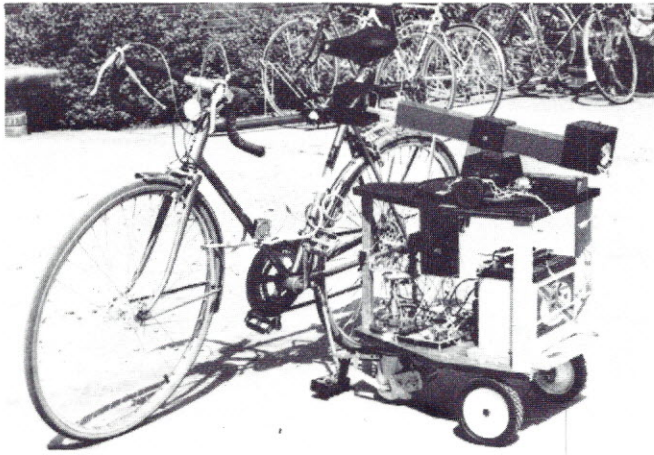


Figure 1. Sparko, a three-wheeled cart built by students of the Robot Group at Oregon State University, carries FP, the arm, up to a bicycle which proves too heavy to lift.

roughly correspond to human arm motions of swinging from side to side across the body (mostly shoulder movement), reaching out (in the human, a combination of shoulder and elbow action but in FP a linear motion), raising and lowering the hand (familiar to any student), and twisting the wrist (try it with your arm extended, and see how many motions are really involved).

The degrees of freedom are the number of different kinds of motion available to the controller of the arm; the number of basic strategies available for putting together a sequence of controls that will move the arm to its desired destination (Figure 3). To the builder or to the programmer of these actions, which must be carefully controlled and synchronized, the amount of work necessary for successful arm operation may suggest that the term "degrees of slavery" may seem more appropriate than "degrees of freedom!"

In industrial applications, some people feel that six degrees of freedom are necessary to do assembly work, while others feel that only three degrees of freedom are necessary for the majority of assembly tasks [1, 2]. We felt that when combined with the mobility of the tricycle, the four degrees of freedom listed above were sufficient for many tasks, and included a sufficient number of interesting types of motion.

## Control

Any robot must, we feel, be able to move to a goal. Sometimes this procedure is very complicated, involving some of the yet unsolved problems of Artificial Intelligence. We are concerned first, however, with a simpler problem. As discussed in the following sections, each of the movements (degrees of freedom) possible has a mechanism and a motor to allow movement. The general control problem which first appears when trying to put these mechanisms to work is: how to move it from one position

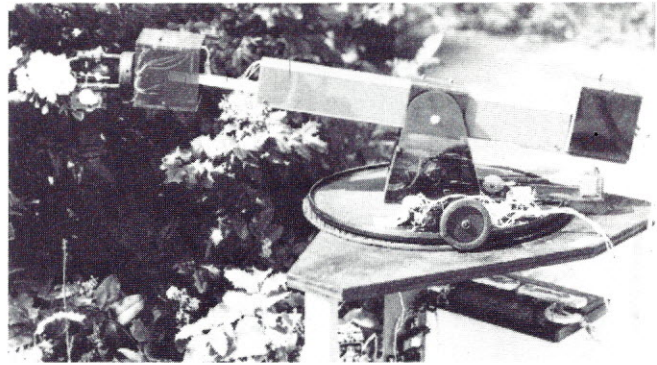


Figure 2. FP was built as an arm to fit on top of Sparko. It can rotate on its "Lazy Susan" base, elevate by rocking around the center support, extend and retract its rotatable wrist and a "hand" capable of grasping small objects such as a flower.

precisely to another, desired position. Once this problem is solved satisfactorily, the robot builder can proceed to sequences of movements, simultaneous movements, and choosing which of the possible sequences of motion is appropriate to reach a goal. (The latter problem can be so complex as to seem unsolvable).

## "Open-Loop" Direct Control

The direct approach to control of a single movement is to turn on the motor for a certain calculated time and then turn it off. At the end of that time, the motor, coupled through the drive train, has moved the object. Ideally, one can calculate just what that time should be for a given

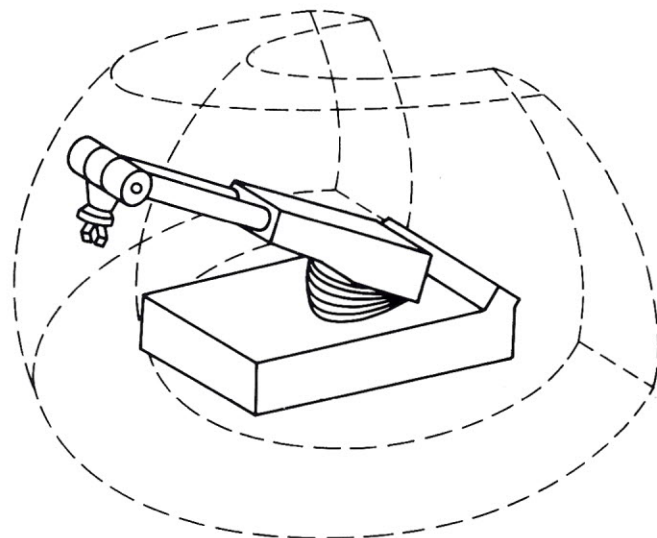


Figure 3. With any robot arm, such as the one sketched here, the work envelope consists of all the space which can be usefully reached by the hand as a result of combinations of the arm's movements in each of its degrees of freedom. A spherical coordinate system is shown.

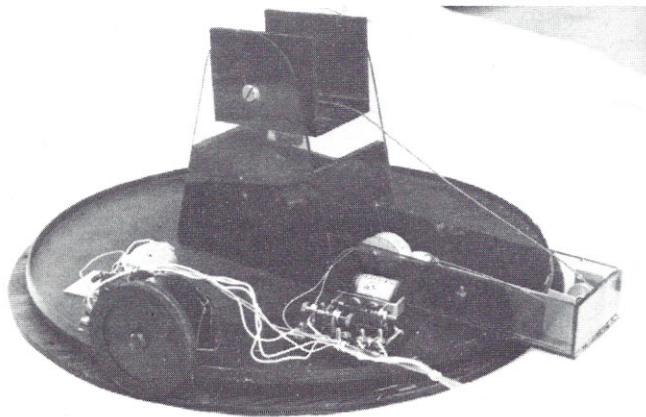


Figure 4. Rotation is provided by a wheel made from a pulley and some foam rubber, and equipped with a brake. The wheel causes the "Lazy Susan" to rotate on its base, and swings the arm from side to side.

motion as in navigation by "dead reckoning." But gears and wheels slip, arms have inertia, real materials bend and shake, and moving the same distance in two different directions takes different amounts of power. We often don't even know the physical parameters of the system precisely enough to make possible the complicated calculation [3, 4], even if we wanted to perform it.

Accurate motion control requires that the actual movement resulting from a command signal is somehow compared with the desired one in a "closed-loop" system that can automatically correct for errors in performance. To illustrate the impracticality of the open-loop control approach for a useful robot, consider trying to get in your car and drive down to the corner store—with your eyes closed.

There are practical applications of open-loop control, of course. One example is the ordinary electromagnetic relay. The coil is energized full on, and the contact moves. When the coil is turned off, the contact returns. In each case, the power supplied is more than adequate to reach the goal, and the moving element has a built-in limit, or stop, at the end of travel. This sort of limited travel between fixed stops has many applications in industrial automation for parts transfer, etc.

## Feedback Control

In closed-loop or "feedback" control, the movement is monitored, and a sensor will "feed back" a measure of progress to the controller, which can then determine how to move in order to get closer to the goal. There is an information-flow loop, then, between the controller, the motor, the moving object, the sensor, and back to the controller, hence the term "closed-loop" control.

One simple type of feedback control system uses detectors at the far extremes of the permissible movements. At the end of the allowable travel of some part is a

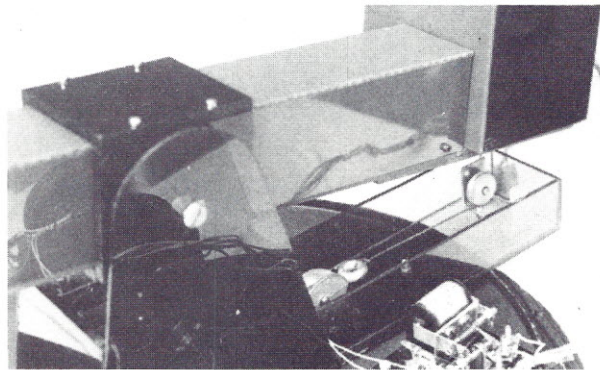


Figure 5. Elevation comes from pulling down the rear end of the arm with a combination of a motorized winch and a couple of pulleys.

limit switch—a microswitch or optical detector. Once the arm reaches maximum extension or rotation, the limit switch trips, causing the controller to stop.

Another more sophisticated approach commonly used is a servo system. The input to the servo system is set to the desired point or path. The controller attempts to match it, driving the load object (the arm, for example) appropriately. As the load lags behind or overshoots the target position, the difference or error signal is used to advance or retard the load's progress.

Feedback loops can be implemented either with digital hardware or in software. The latter approach is the most flexible, and is commonly used in robots. Here the robot controller senses or observes the movement of its own part in relation to the goal location. Control of the motors, particularly when close to the goal, can be computed from the difference between present position and goal position, etc. This feeding back the measurements of actual motions to the controller is the sort of function that a servo system performs automatically, but the software control method can be used where hardware servos are not available or not practical.

One example of this form of feedback control is employed in our experimental robot. The powered wheel on Sparko has reflective foil spots around its rim, and a photosensor detecting them can report the robot's progress. If Sparko is commanded to go, say, twenty feet down the hall, a subfunction can count turns of the wheel. When the counting nears the equivalent of twenty feet, this subfunction could slow down or begin to stop the wheel motion.

Difficulties in using the software form of feedback control include the difficulty of finding and interfacing a means for monitoring motions and relating the measurements to a meaningful frame of reference, the sophisticated mathematics sometimes necessary for attaining ideal behavior, and obtaining the proper timing of measurements and feedback control computations.

Nonetheless, future developments of Sparko and his arm are planned to include more such feedback schemes, using optical sensing (vision) and acoustics (sonar).

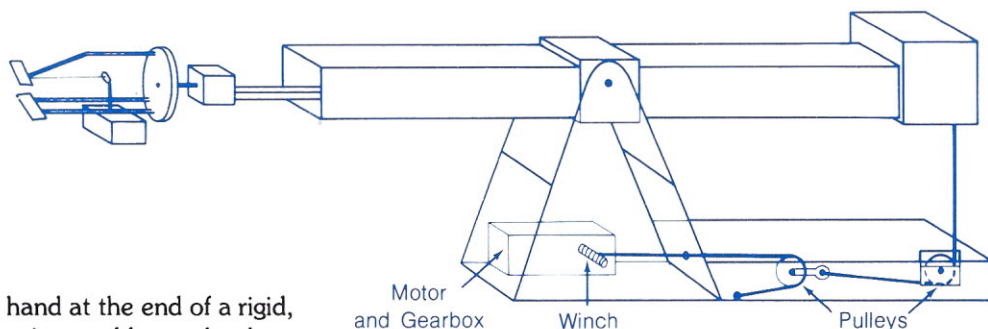


Figure 6. A sketch of FP showing the elevation mechanism, with the wrist and hand mounted ready to slide in and out.

## Construction

We begin with the notion of a hand at the end of a rigid, straight arm. The following sections address the low-budget construction of mechanisms to give it motion in a spherical coordinate system.

### Shoulder Rotation

One of the handiest items in our parts bin was a turntable. Because it is large, all kinds of things can be mounted on it, including the arm itself, and the drive motor and gear box for turning. There is enough room for future addition of microphones, sonar transducers and a digital TV camera. These items roughly correspond to hearing, depth perception and vision. In people, these senses are mounted in a turnable head. Even though in humans the arm doesn't rotate with the head (unless you have a stiff neck from a bad night's sleep), it would make sense for a robot to have these mounted on the rotation platform along with the arm. This saves having to build another platform just for the sensors.

The base of the platform is a 15" plywood circle. On top of the wood base is the rotation platform. This is a simple turntable (a Rubbermaid "Lazy-Susan"). This turntable consists of two surfaces separated by ball bearings in a grooved channel. (This arrangement is sometimes called a *thrust bearing*.) The entire platform is driven by a friction wheel turned by a small motor and gear box. The motor and gear box (like most of the other in this project) came out of a broken toy (Figure 4).

The motor and gear box are mounted near the edge of the platform, with the drive wheel extending over the edge. The radius of the wheel is just a bit more than the distance between the center of the wheel and the base. This helps insure good contact between the edge of the wheel and the base.

The drive wheel is made from a pulley. On the outside edge there is a strip of 1/4" foam rubber for traction. In addition to glue to hold the foam strip on, there is a tightly wound wire around it, forcing it somewhat into the edge of the pulley.

The platform rotates well, but one problem to be kept in mind is momentum. This could be taken care of either with position feedback and correction, or a system for stopping, or both. Stopping can be done by reversing the motor momentarily, or by a brake. Since there was a brake in the parts box, that's what was used. There are a couple of problems in stopping a system. One is that attempting to quickly stop a moving mass puts a lot of strain on the

structure. Second, it is difficult to instantly stop any mass. Remember that this gets worse when the arm is extended, or when weight is added to the end of the arm as when it is holding a payload.

While the platform could rotate 360°, its movement is currently more limited. The cables from the motors and feedback sensors are rather bulky and hang off the back end. This limits its rotation to  $\pm 45^\circ$ , which for our uses is entirely adequate.

### Elevation

At this point, our robot can move its rigid arm from side to side (shaking hands with this robot would be impossible—unless you were lying on your side). It would be nice to have it be able to pick things up or move things from one plane to a higher one. Performing tasks such as washing dishes or picking things up from an assembly line requires an arm which can move in a vertical direction.

Moving in the vertical plane can be done by raising the entire arm—as in an X-Y-Z coordinate system. Devices such as elevator mechanisms or screw drives could be used to do this. We designed our arm to be rotated in a vertical plane rather than be raised and lowered in it.

This rotation could be done by attaching the back end to the platform and raising and lowering the front end. This creates a few problems. One is that the front end can't be lowered below the base. But the most important is the weight problem. The drive system must support all the weight. In hopes of avoiding some of these problems a fulcrum method was used. The arm is mounted with the center of balance just in front of the pivot point. This way gravity would provide the downward force. For the raising action we used a winch. The winch was housed under the fulcrum and the cable ran along the platform to a point directly under the "back" end of the arm. The cable then ran around a pulley and up to the arm.

When the winch is turned on, the winch begins winding the cable and the back end of the arm is pulled down to raise the front end. Some of the workload on the winch can be reduced by sharing the load with a pulley system. (Figures 5 & 6)

The vertical rotation of the arm is limited by the support structures. It can be lowered until it reaches the edge of the platform, about  $-22^\circ$ . It can be raised until the back end reaches the pulley box, about  $+15^\circ$ .

## No Elbow

Now that we can get our hand to any position on a portion of the surface of a sphere, it would be nice if we could also move along the radius. With this, we could access anywhere in a space bounded by its rotational angles, outer radius, and inner radius. Some of the commercial robots use a joint in the middle of the arm which resembles an elbow. As humans we use a combination of shoulder and elbow movements to position our hand between our shoulder and the end of our reach along a linear track. However, in keeping with the spherical coordinate system we have chosen, our arm telescopes in and out in the radial direction instead of using an elbow.

We mounted the wrist and hand at the end of a 40 cm push rod. This rod was set into a 45 cm U-channel so it could track easily. Some roller bearings were strategically placed to cut down the friction as the push rod moves along the track. Attached to the U-channel, at the end opposite the hand, are the motor and gear box. Viewed from above, the output shaft of the gearbox is in line with the center line of the channel and rod. The output shaft is connected to a threaded drive rod. This drive rod runs up to the front where it terminates in a bearing assembly. This

should be carefully checked for proper alignment. The back end of the push rod is attached to the drive rod by a nut, which is prevented from rotating by mounting it in a block which is fixed to the push rod. (Figure 7)

If everything is properly aligned, the whole mechanism should operate without binding. As the motor turns the threaded drive shaft, the nested nut is driven longitudinally. This in turn moves the push rod and hand. The whole action is guided by the U-channel.

The entire mechanism should now be able to slide in and out, giving the extension effect which a human achieves with shoulder and elbow.

## The Hand and Wrist

The hand is the business end, the part that adds usefulness to the arm. Usually this is designed to grasp (or pinch) something. Often this grabber is made to be detachable so that some special-purpose mechanism be added. Some of the commercial machines have paint sprayers or welders which attach to the end of the arm. But for us and most other experimenters, a general purpose grabber was the most useful.

Our grabber has two foam pads about an inch and a half apart. Imbedded in one pad is a small light and in the other is a photocell. This way we can tell when the grabber is positioned right, and it keeps us from getting a handful of air.

The pads are brought together by a lever action

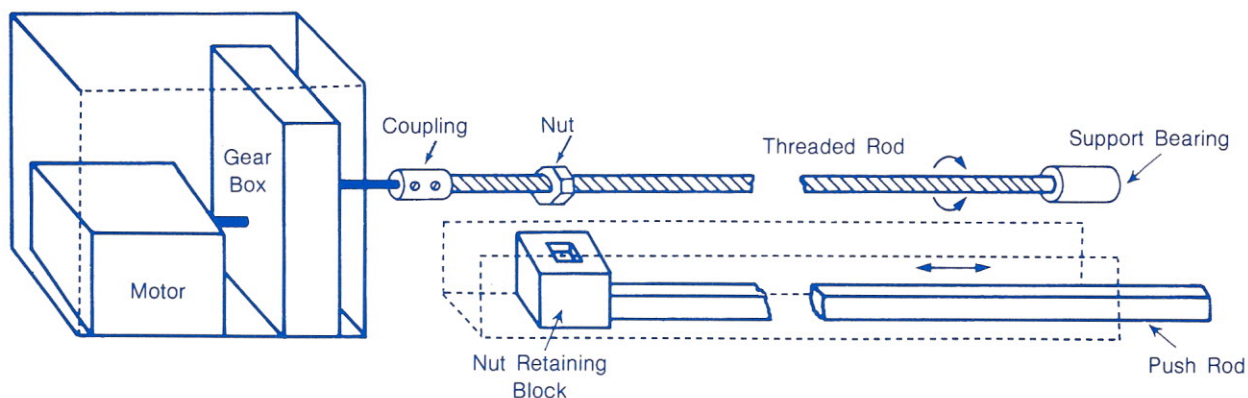


Figure 7. For extension, a push rod slides in and out. The back end of the push rod is fixed to a nut, which moves along the length of a threaded rod as the threaded rod turns.

(powered by a geared motor) and squeeze the object. With this arrangement we've been able to pick up and hold pens, pencils, soldering irons, coffee cups (very light ones), chess pieces; and to pull light switches and to flip switches on a computer. (Figure 8)

The grabber can be a simple structure with no degrees of freedom, or it may have several degrees. For Fanny Pincher we decided that one degree (the wrist) would be enough to do most of the tasks we had in mind. With this much, once it gets hold of something it can turn it (like a knob or screwdriver) or tilt it (like a test tube or cup of coffee). This allows enough activity to keep several programmers busy for a long time.

The wrist is a rather simple device. It is simply a motor and gearbox attached to the end of the push rod. The output shaft of the gearbox is attached to the hand. The wrist can turn several revolutions. The only limiting factor is the cable from the hand, as the wrist rotates it winds up the cable. Our configuration permits a  $\pm 540^\circ$  range of motion.

## Summary

We have presented here our design choices in building a "no-budget" hand and arm for experimental robotics study. Providing controls through a computer interface has proved relatively easy. Very important in making this

control accurate and useful will be the implementation of feedback sensors on the manipulator joints. If we can measure progress of motion in a given degree of freedom, we can better control the "reach" to a desired position, and perhaps pour from the pitcher into the glass rather than onto the floor!

A more involved long-range project is concerned with the higher levels of organization in the general robotics problem of achieving goals in terms of sequences of actions. Meanwhile, we will continue to enjoy the implementation problems and their solutions. □

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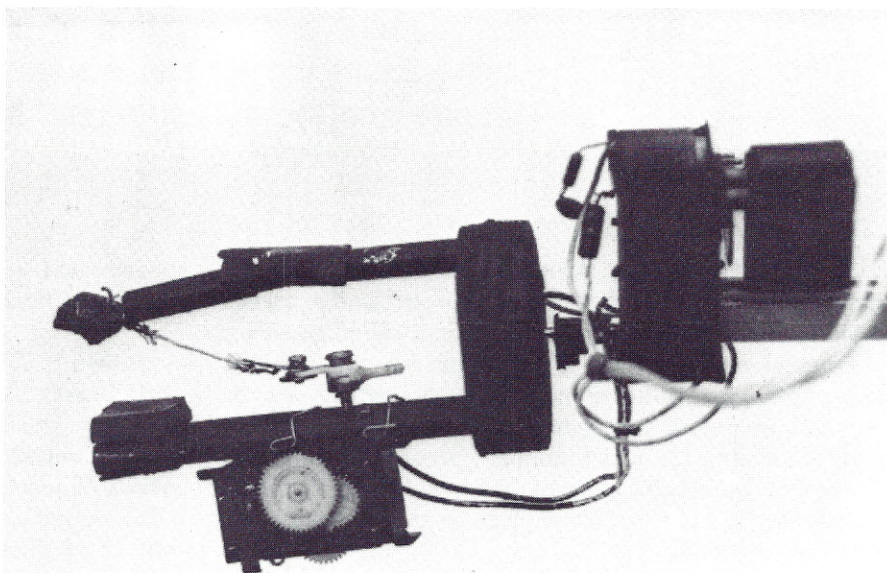


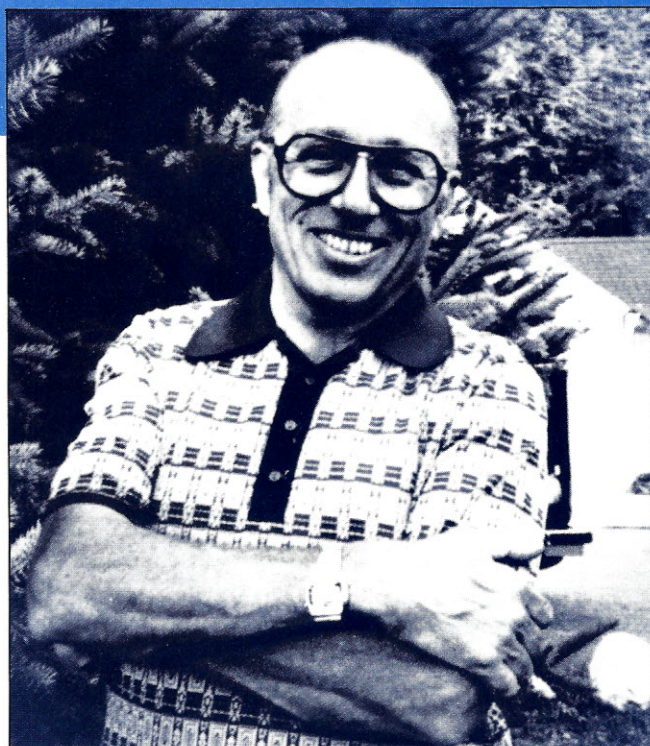
Figure 8. The business end. Near the front end of the arm, one motor rotates the wrist to bring the hand to any desired angle. Another pulls tight the short cable or sinew to close the padded fingers.

# ROBOTICS AGE INTERVIEW SERIES

By Jerry W. Saveriano

## AN INTERVIEW WITH

# JOSEPH ENGELBERGER



Called "The Father of Industrial Robotics," the founder and president of Unimation talks about the formative years of the industry and the forces behind its growth.

*Joseph F. Engelberger, widely known as "The Father of Industrial Robots," is given credit for being the prime mover behind the creation of the present robot industry.*

*Founder and president of Unimation Inc., the world's first and largest robot company, Engelberger's efforts to establish the industry have been recognized by the Robot Institute of America which annually presents the Joseph F. Engelberger Award to "a person who has contributed outstandingly to the furtherance of the science and practice of robotics."*

*In this interview by **Robotics Age** Industrial Editor Jerry Saveriano, Joe candidly discusses the difficulties and excitement of the early years of robotics, and the*

*people and events that played an important role in building a new technology.*

*Joseph F. Engelberger was born in Brooklyn, N.Y., in July of 1925. At age three his family moved to Connecticut. His family struggled through the depression. Joe's mother advised him to "carry in his head most of the assets he would have the rest of his life." He heeded this wisdom and was a good student in high school. He was one of 14 physics majors selected from throughout the U.S. to attend Columbia University's special V-12 (accelerated college and officer training) program where he received his B.S. in Physics. After WWII he returned to*

Columbia and was awarded his M.S. in Electrical Engineering. Since then, Joe has capitalized on his assets and has built for himself an important position in the history of robotics.

#### *How did Unimation start?*

I was working in the aerospace industry in Bridgeport, Conn., after getting my master's degree from Columbia. Twelve years later I had a falling out with the company I was working for, and while the details of the falling out are sordid, it turned out during the infighting that I was given five months to raise the money to buy the business I was running for these people. In due course I found an entrepreneur, Norm Schafler of Condec, who put up the money. Fourteen of us had shares. We ended up friends with the original owners when it was all over—because they got a good price and I got a good business.

#### *How old were you at this time?*

Thirty-one. I spent four very unusual months of my life finding the support, and then we got going. We moved into a former garage and started Consolidated Controls. We were in the black in seven months, and we've increased the earnings every year since—that's from 1958 to date. That was the beginning of Consolidated Controls, from which Unimation was a spin-off. Both are now part of Condec.

#### *Consolidated Controls made controls and valves for aerospace?*

Right. I suppose the connection with robots may make sense if you look back and say: What do guys involved in sophisticated aerospace work do? Well, one thing is servos. I had the first course at Columbia University on servo technology, and there were a number of people who helped start the company who had servo background, which didn't exist before World War II.

#### *Servo technology helped in building the first industrial robot?*

That's right. We also had some control system knowledge, and in 1958 we made up our minds to make a robot. Really though, Unimation got started back as early as 1956 when I met one George Devol at a cocktail party. He had some patents on programmable manipulators. We had this

wonderful idea: why don't we make a machine for factory automation, but in a different way than it's usually done?

When you automate, usually you look at a product and say, how will I make that *particular* thing automatically. It's a simple decision if it's a Coca-Cola bottle, because you're going to make them the same way forever. So you make a machine that's going to spit out Coca-Cola bottles. But if you're making an automobile, for example, you know you've got variations on the theme in the car—all kinds of batch manufacturing problems that don't easily succumb to automation. So the idea was, let's not look at the product, just for once let's look at the people. What do they do? We surveyed seven plants of Chrysler, six plants of Ford, and five plants of General Motors.

#### *Who participated in that first survey?*

Some of the people from Consolidated Controls. Largely Maury Dunne, who was chief engineer, and George Devol, who was working with us.

George is a fabulous character who had a very big role in electronic counter measures during WWII. At the end of the war, he had one of the first control companies in the United States, but his partners kind of eased him out. He worked for RCA for a while, and then he had this idea—about industrial robots. He tried to present this idea to company after company. Unfortunately, he came across as something of a wild-eyed inventor. Of course, the inventor is important, but it takes an entrepreneur to make a business, and so he didn't get the financing. In fact, he came to the company I worked for three years before I met him, and they turned him down. Later I convinced them to take a license under George's patents. When we started our own company we took that license with us. Since we took all the engineers with us there was no point in the original company keeping the robot license. George Devol kept his patent work up. We added lots of patents. We now have 45 allowed patents, and 2,000 allowed claims. Generally, that's enough to get people to take a non-exclusive license if they invade our turf.

#### *Is George a tremendously bright engineer and inventor, who came up with an idea out of the blue, or was this the right time, was he at the right place, looking at the right things with the right kind of technology?*

First of all, George is a very, very bright guy. But he is somewhat primitive in the sense that he is not formally educated. Nevertheless, he ran a 3,000 man organization in WWII, and he's very good at picking other people's

brains. He had this robot idea because he had control background, and I would say he is very intuitively clever, but not all that great on execution. He can wave his arms and say, "I've got a feeling in my gut!"—and this feeling is good. I think the two of us were a great combination. I would say, "George, I don't think we can hack *this*, but we could hack *that*."

*Was his idea not something that was conceptualized from scratch, did he basically assemble existing technology?*

Yes and no. He had some new ideas on magnetic memory and on how a programmable arm could work on a digital basis—which is important because no one thought digitally yet. Being in the computer field he knew a lot of these things and he would couch them in the right terms and make his patent applications.

*Was the idea of an industrial robot his?*

I think so. Of course, the idea of robots is certainly a lot older, but he did have the idea of an industrial robot first.

Personally, I had been fascinated in college by Isaac Asimov. He was a very young, prolific writer at Boston College at the time I was at Columbia. I read his stuff and that got salted away, along with a lot of other science fiction—and then I've got a physics background. We were in aerospace doing servos, jet engine controls, and then I meet this guy that says, "You know what would be a good thing, if we could do it?" And I'm in the business to say, "Yes, I think we could do it!"

We made what I think were some good decisions on what ought to be. We went digital when many people were analog in their thinking. We worked solid-state, and that's such a trivial thing today. We went solid-state, when if you did the same thing we did then with electron tubes it would have cost twenty percent as much. Transistors were \$1.70 and an electron tube was 30 cents. We said, "Well, transistor costs have got to come down," but I can guarantee you, not in my wildest imagination would I have thought as far down as a fraction of a penny per function, which is where we are now with chips. It would never have occurred to me. We just said, "Hey, digital is the right direction."

*So you recognized at that time these things which later became an important advantage, even though they weren't being done at the time?*

Yes. Not only that, other companies were trying to build robots, too. Before we started Consolidated Controls and were still with the old company, I had already started this robot activity. When you try to raise money you spill your guts to anybody who will listen. You tell them everything you know in hopes you'll get money. I got a hell of a lot of people interested in our robot ideas.

Another interesting thing happened at the same time that I was looking for money. Ford realized that I was no longer getting the support that I had from my previous employer, and they felt that the work we were doing with robots was important. The guy who was most interested at the time was Del Harder, a senior manufacturing executive at Ford. It was Del Harder who coined the word *automation*. He was all excited about robots and told the chairman of the board of my employer that he could use two thousand of them tomorrow. This was in 1956.

He was a big gun and a driving influence. His side kick at the time was a fellow who is now executive vice president of Ford International, Jack McDougall. Somewhere between them they thought I was being abandoned but the idea of robots shouldn't be. They took the exact specification we wrote (and this is the honest truth), wiped our name off and put their name across the top. They sent it out to companies they thought might be interested in robotics.

So there it was, going out to American Machine and Foundry, to Borg-Warner, to Hughes Tool, General Mills and others. It just so happened I was going in the back door while Ford was coming in the front door. So they have a spec that comes from Ford, and they have a young clown coming in who says he needs money to do something just like it. Surprisingly enough, every one of those companies started robot businesses, even though we didn't get their support. They started to build robots because they thought it was the right idea and they had the spec from Ford. But every one of them went analog!

*When you first went out with the idea of robots—George sold you, and you said, "I agree, that is a good idea." When you went out and tried to sell the concept, of the industrial robot, what kind of reception did you get?*

We started with the first plant surveys we had done in 1956. In 1958 I was raising money to start a company using the robot concept as part of the proposal. We made controls for jet engines, and for nuclear power plants, but the biggest draw was the robot concept. The various companies that I talked to all salivated over the robot.

They bought my pitch. They bought the whole thing—the thing we said was going to be a good business one day, but then they would not buy the aerospace business. I would not sell without it. So they all set up their own little private organizations to try and develop robots and each one failed.

*After hearing the idea of the robot, did everyone really agree it was great?*

No—not everyone did. Investors did. Customers didn't. There's a big difference!

*But you had much better success than George had, going out convincing people that this was a real product.*

Yes. But that happens to be my forte. First of all I was excited about it. You've got to be very excited yourself. I really believed. George also tends to be more difficult to pin down for specifics. How are you going to do it? What are you going to do? I was able to say: this much organization, this much money, here's what we're going to do, here's the market—all these things I thought out. I was wrong, too, but at least I could tell them something. The other people did half-baked ventures and most of them abandoned them. The only one that stayed in there for any length of time was General Mills, who had probably the best technical answer at the time, among our competitors,

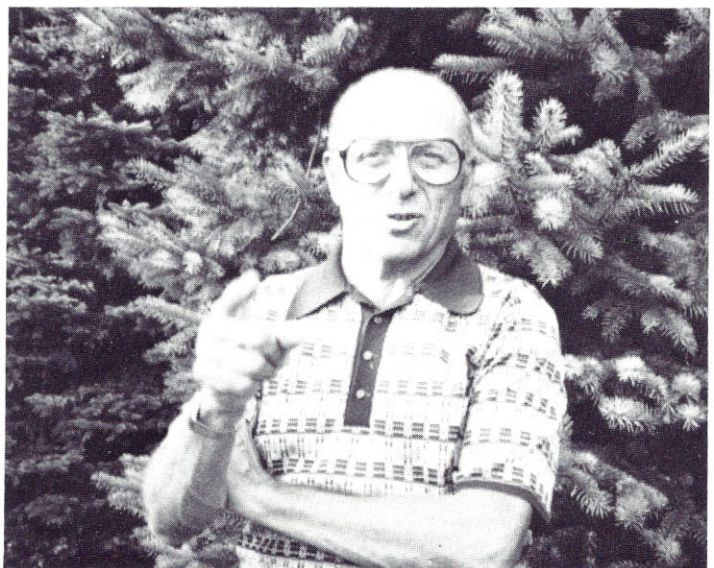
but then they decided they didn't want to stay in the mechanical business anyway. AMF would have been the top dog, perhaps, if Patterson had stayed alive. He was the man who made the pin spotter go, you may recall.

The most important thing to me is perseverance and the ability to stick in the face of adversity. This seems to be more important than technical acumen and anything else. You look at Wilson, of Xerox. What he did was contrary to every consultant's viewpoint on what was necessary in copiers. As he said, "In the end, it's always an act of faith." And it was for him. Also for Land of Polaroid and for most people in technological innovation.

As an aside, I can go beyond that and say there is no hope of anything in the field of technological innovation ever getting anywhere if the company is controlled by financial men. The difficulty is that the financial man is unable to think in terms of intangibles, and secondly, he can only think on a discounted cash flow basis. So, if you look at xerography, for example, and at the Polaroid camera, piggyback railroads, and NC machinery—I could go on and on because I studied a lot of them—they did not reach fruition in sufficient time for a discounted cash flow analysis to justify starting. I can go further and say that if a company doesn't do some things on the basis of long term rewards, it may not even survive.

Suppose an ROI standard controlled by a powerful financial department demands a 25% return. A future return 10 years hence can never justify current investment

**"...If you somehow take away from the designers their god-like role on function and appearance and get them to listen to the people who make it, it would be ideal."**



on that basis, but I think it's dawning on the financial types that we're selling our souls for short term benefits.

*So you've started the company, but you haven't built that first machine yet.*

No, we struggled with designs, we hired professors to work on some ideas we had, we did as much as we could with limited resources. We got our first machine together in 1961. It went into a plant in Trenton, NJ, of General Motors.

*Tell me about the first robot.*

You'd be surprised how close in appearance it is to the latest 2000 series. It had aluminum covers instead of fiberglass covers, but it had the same physical construction. It was a five-axis machine like a five-axis 2000, and to me this was one of the most important things because I was just asked today if people won't make three year commitments like the Japanese do because they're afraid they'll become obsolete. I said, "What are you talking about? Obsolete? The machine looks just like it did in '61. It's got a little bit better control system, of course, but the first machines are still working! They've got 50 man-years of work and we've overhauled them, but they're still working! You're going to start worrying about obsolescence?"

*What was the feeling then? Who was the crew? Was there a scene where you plugged it in and somebody hit a button, or was it just so many pieces being assembled that there was never one particular moment when it started working?*

We put it all together with a crew of about eight people, and eventually we started simulated jobs. We made the typical stamping runs, things like that—all simulated. We poured more coffee and drinks for the press. Vast amounts of publicity. You'd be surprised—you figure the publicity from 1961 to now has been overwhelming and yet there are plenty of people out there (manufacturing people, by the way) who've never heard of a robot. How the hell they're going to hold their jobs down I don't know. They may not want to buy one—I can understand that, but not to have heard of it means they're just not even reading their trade magazines.

*But, didn't you have—I don't know what you call the experience—James Joyce called it an "epiphany," or an*

*"ah-ha!"? Like when Frankenstein was working on the monster and he saw it move—"It's alive!" Did you stand back when you first started and exclaim "We've made a robot!"?*

No, it didn't work like that. It was certainly a slow growth process. We did one articulation at a time. We worked on the memory, and on the environmental constraints. You don't have a robot if you have a 30 hour mean-time-between-failure machine. We wanted a reliable machine. It was going to go in a factory, do the work, and live in that environment.

There were certainly no "eureka" moments. It was an agony. We got to a position where we knew it was going to

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**"...This is a very important thing  
that never dawned on us to begin with.  
Nobody needs a robot. What a sad thing!"**

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happen. It was just a question of the dirty details of making the thing work, and when it finally works, it has got to work consistently.

Look at the reliability of an NC machine tool. The whole NC thing really started in '55. Forrester had finished his work at MIT, and it looked like it was possible. The Air Force did it all; the machine tool industry did nothing. Given the potential savings, the equipment was worth buying with an 80% up-time. But it turns out you can't live with 80% up-time of a robot, you've got to have 98%. You have a domino effect. Machine tools stand alone, someone decides the throughput is only this much, that's all that's needed, let it run this much and you get that throughput. So they never had the pressure.

Suppose you have a \$500,000 press or \$300,000 in a die-cast machine—if the robot goes down another machine is down, you're losing capital benefit. Not to mention that putting a robot on the factory floor is a little different than putting a computer in an office. You get a lot of people very nervous who have no background in electronics and controls, and it's even worse than it was for NC because NC machines were normally put in an air-conditioned room with engineers handling them.

*It also becomes part of a system and it just doesn't go down by itself. It takes other machines down; work flow stops.*

It interfaces. No question. And another thing is—no one needs one. This is a very important thing that never

dawned on us to begin with. Nobody needs a robot. What a sad thing! You see, if you need more capacity to cut metal (milling) you can't have people there carving the metal with pen knives. You must have the cutting capacity, so you buy it. Who cares? That's why people in the machine tool business are order takers and not salesmen. They wait till somebody needs, and then they're ready to take your order.

But almost without exception, a willing, industrious human being is always better than a robot. The American Manufacturer goes for the bucks. If he doesn't save money there's no need for a robot, he can do everything he has to do with people. The only thing that motivates him is saving money. But on the other hand, he doesn't even need to save money if the other guy, his competitor, is not saving money. So why should he buy the damn thing? It's going to be a pain to figure out how to use it. We need the leverage of someone using it and using it extensively. Now, the next guy needs it! He's going to need it to keep up. The institutional job was just unreal. We never believed it would take as long as it did to sell the concept of the robot and the product.

*Let's get back to the first robot. You finally got it running, and reliable...*

It was hydraulically powered, had a digital control and a magnetic drum memory, and used all discrete solid-state control components. It had the teach control that we now use mounted right on the end of the arm, and you pushed the arm through a teach control button in any direction you wanted it to go. The catch phrase was, "you take it by the hand and teach it." You did literally take it by the hand

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**"...Almost without exception  
a willing, industrious human being is always  
better than a robot."**

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and teach it. It made a lot of sense to us, except that if you stick the hand in the middle of a press, you can't get your head in with it. That's why we pulled the teach controls off the end of the hand and put them in the hand of the programmer, because it had too many constricted places to go to. It had a memory of, I believe, 180 steps, though we couldn't divide up the programs. It had 5 ins and 5 outs and slow speed positions we could teach. That, in a manner of speaking, is the heart of what's necessary, because that same machine was going to do die-casting, forging, and machine-tool loading. By '64 it was also doing

spot-welding—all with no more than those capabilities.

*What was your idea of a robot? You had a programmable controller and a servo arm.*

A servo arm, but a programmable controller is not exactly the right way to describe that portion of it which was doing the sequencing. The arm control and the memory of the taught positions was really in a special purpose computer that we had built. Remember, at the time we could have bought a five-axis controller for a NC machine for \$35,000. We would have had a \$35,000 box of tricks to run our \$40,000 arm, adding up to a \$75,000 raw cost machine. The market price was about \$18,000! We built the electronics ourselves for about \$3,500, that's 10% of what it would have cost to buy an NC machine controller at the time.

*Who was your first customer?*

The very first customer was General Motors in its Turnsted plant. The robot ran a die-casting machine. We never got a chance for another 12 years to do what we wanted to do, which was to load machine tools. We thought that customers shouldn't buy a big custom parts transfer machine, they should buy general purpose machines and then use robots in-between them. Then they could make anything.

It seemed quite rational, except no one would let us do it. They told us there were chip-breaking problems, there were plant layout problems, all the reasons why it couldn't be done. It became apparent that there wasn't any hope to get this equipment in, unless the introduction cost was very slight and the risk was very slight. When you are designing an entire plant, you would, for example, use transfer machines, spending millions of dollars in plant layout. The robot technology was too new to gamble on.

On the other hand, a die-caster might say, "There's an open space next to my die-casting machine, and it's a lousy job—if the robot doesn't work, I can throw it out, so I'll gamble a few months to try it."

*Was the reluctance due to the so-called "machine-tool mentality"?*

Well, the attitude was that the robot was new, and we're not sure it can hack loading and unloading machine tools. Therefore, let's stick to conventional technology. Another thing was that, at that time, engineering was still relatively cheap. Machine tool companies wouldn't do business with

us either. We'd say, we'll sell you the robot, you'll sell it with your machine tool. Ahhh, they said, I'll go design a special loader/unloader, and I get the volume internally using my own direct labor. They could get away with it because at that time a loader/unloader was probably cheaper than our robot. We had a lot of sophistication they didn't think they needed.

As time went on, engineering became more expensive; so now they had to put the engineering in and design a special purpose loader/unloader, going through all the debugging costs before delivery to the customer. Today they're better off to get a robot in the first place that's been fully debugged and is virtually off the shelf.

Another thing is that the built-in loader is a dedicated robot. But in a lot of systems you don't want a dedicated robot, you want a robot that can tend three or four machines, can tend buffer storage in-between, and can do lots of other things. That's the concept that's become very big. And it's only been in the last few years. I think 35% of our present quotes are for machining centers.

Back in 1962, there was no such thing as computer-aided design; no one was using computers in manufacturing. All the system thinking that should have been involved at that time just didn't exist. We had a stand alone machine, and we didn't have the system thinking either. So we had a "solution looking for a problem," and we found the problems in die-casting and in punch press operation, plastic molding, and spot welding. We started spot welding about 1964 when General Motors wanted to try robots on a line in Norwood. We put a couple in, and they ran for two years before we got any further business. Then they came along with a shot—we'd been making two, three a month—and wanted 66! That always strikes me when I watch that old Johnny Carson show. He asked how many machines we made in a month, and I said, "20, this month," because shortly after we got through making those 66 we were back to making 4 a month again.

*You appeared on the Carson show in 1966. What was the response to this mass public exposure on TV?*

Well, we had a lot of little TV shows, but that was the first major one. It was just all kinds of fun. We did it in California. The gag line was that the robot could take over the show. Because the first thing we did was putt a golf ball, and Carson couldn't putt that well. Then we did the beer commercial, and Ed McMahon wasn't necessary, right? Then we lead the orchestra, so we didn't need the orchestra leader.

They've played it many times, and it was a great gag and all that, but the only known benefit I have from that whole

thing was a couple days later when I was driving my Avanti to the airport. The windshield wipers went out, and it was pouring rain, so I ducked into Norwalk with my head out the window, pulled into the Hertz place there and said, "I've got to have a car to get to the airport, and my windshield wipers are gone." The guy says, "No cars—just don't have them." I said, "Oh, my god." And the manager, who was sitting in the back, looked out the door and said, "Hey, Christ! That's the robot man. Give him my car." That's the only benefit I know of that we got out of that show, except that we have fun using it at training sessions. We have learned that very often you deal with the general public you're not dealing with your marketplace.

*Do you feel, though, that although they're obviously not going to be buyers, there's some conditioning of the public that needed to be done?*

Never felt it. No need for conditioning.

*In all of Asimov's books that I know about, robots were either looked down on, or weren't even allowed on earth to operate because of the attitudes of the public. Didn't you have any concerns that they might even be rejected outright?*

I might have harbored a concern, but that's got no connection with reality. It's not an issue. The public doesn't give a damn. Even today it doesn't give a damn, and we've got to look at today. Today we've got vast publicity with all kinds of science fiction movies and all, and the attitude is largely benign. The problem I can tell you we have is with management. Absolutely with management—it always was with management, and it still is with management—not the public at all.

So we didn't get any benefit from public exposure, though we didn't get any disservice from it either. There was always interest. Whenever I got an inquiry from the unions, I would politely go and talk with them, if they wanted to know about robots. It's a terrible thing that you have executives in executive quarters sitting in deep pile carpet whispering "robot" to each other like it's a dirty word. The people on the floor don't give a damn for that.

Management attitudes are terrible relative to productivity! That's a sad fact. Management has a tendency to blame labor and the government. The government is ridiculous. On the other hand, in many cases you can get around the government edicts and get on with it anyway.

*It seems to me management is always going to have an adverse environment, and to some extent it's its job to find*

ways over, around or through it.

I think it's perfectly reasonable to do the job without causing massive displacement. I don't see any reason why we have to throw large numbers of people out of work in order to improve productivity. I think it can be done gently. The farm industry did it from 1870 to 1970—that's a hundred years—we went from forty-seven percent to four percent of the labor force in farming. There were disruptions—people moved to the cities—dislocations did occur. But if you decide to get all the people out of blue-

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**“...The problem we have is with management,  
...it always was with management,  
and it still is with management—  
not the public at all.”**

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collar work to that extent, you won't get them all out. You'll do what the Japanese are doing in their MUM project (*Methodology for Unmanned Manufacturing*) and end up with a minimum of blue-collar workers and a maximum of knowledge workers—that's the goal.

I think that if you do it in a reasonably gentle fashion that it will work. I think the magic thing should be: do it no faster than the attrition rate. That's retirements, pregnancies, and wanderlust, whatever it is that makes people leave their jobs. A robot happens to fit into that very nicely, because it does so many different things. It's not like automating a meat packing plant, for example. In an automated meat packing plant you change everything, and you shut one plant down and open another one up. The automation is in the new one, and all the butchers are in the old. They're 55 years old and making, whatever it is, \$9 an hour as a butcher, and they're offered \$3.50 an hour as an electronics technician: “We're going to retrain you.” Big deal! You can't do that—it's too harsh.

*And with a robot, you can use that incremental approach.*

Yes. Just a little bit at a time. Give them jobs that either weren't done before or that people don't want. A dull job is just perfect. Make a deal with the union, introduce the machines as people retire at the die-caster machines. One place has been doing it for ten years; they now have 37 machines. Two years ago a union president took me to dinner. He says they've got so many more jobs since the company has grown more successful. All those guys at the die-casting machines were immigrants—mostly Middle-European. Their kids don't want any part of that job

standing at a die-casting machine. The transition to robots can be done and it will be done.

Perhaps you saw that MacNeil-Lehrer show I was on. The social scientists can dream of more things to worry about that will never happen. I'm very skeptical of all kinds of technology assessment. That may make me seem very reactionary, but having been on the other side trying to forecast how to do something I want to do I can't imagine anyone being able to forecast what the secondary effects are going to be. I can't even be sure of what the primary ones are going to be, and they're saying this is what's going to happen! What you should do is get on with what you think is valuable, and when you find out there's a secondary bad effect, fix it. I'm a firm believer in the technological fix.

*You don't think some advanced planning in research and modelling, though social modelling is difficult, isn't valuable?*

I'm very skeptical, because I don't think you can build the model accurately enough and you can't introduce sufficient data. The data is not going to be very good either.

*You're not so worried about technology?*

I'm not worried about technology. I think that the salvation of the world is in the hands of technologists—has been, and always will be.

*And also on the other hand it could be the destruction if not properly applied.*

Hey, you can blow the world up with a nuclear bomb—I understand that. I don't think you can do very much by saying let's undo it and go backwards. We take great risks with the ability to do great destructive things. For example, there's another new thing, right at the moment, this vast land of genetic engineering. Should we stop this work?

Or, there's a guy named Delgado whose work is akin to the robot business. He's in Spain now. He left the United States because he was working at means for motivating monkeys. I'm not kidding! He went to Spain because the Spanish Universities will support his research, and they wouldn't worry about SPCA rules and all that. There's no question in my mind that if you could find a way to sufficiently motivate a monkey to work in a factory, through electro probes or whatever, he's going to be a hell of a lot better robot than I'll ever build. The finger dexterity of a monkey is unreal.

After all, the way we treat animals is grotesque anyway. We treat them like a commodity. We think of a chicken as an egg factory, and the pigs! The way they kill them, and so forth. All that's ok? Compared to that, what would be wrong with having pleasure probes put in the brain of the monkey, putting him at a machine, and letting him build stuff. I think that's just as logical. So Delgado went to Spain. He's a good researcher; his research may or may not be fruitful—I don't know.

*That's funny. Well, we've covered the middle years when you started having success with the automobile industry. You had machines on the job running.*

The basic business grew out of the automobile industry. With us, as with anybody else. The automobile industry is about 55-60% of the market. Other people are coming up, the applications are there, but the big volume is in automotive. Their product is perfect, and the pay scales are right. The attitude of management is as good as you can get it, even though it's not perfect. It's the industry at the moment.

*What industry should be using it, desperately, but is not using it? I mean, where is there a screaming need for robots that is just being ignored? Machine tool loading?*

Any kind of machine tool loading is one place where a screaming need exists. That's across all kinds of boundaries. We don't tend to look at a market until people demand that we look at it. We mostly look at it from a

functional point of view. What jobs are there? We do an awful lot of spot welding. Yet, the arc welding business has got to be 20 times as big in the United States. Unfortunately, the arc welding business is more demanding technically, and we've got to solve a few more problems that probably involve adaptability. We've got to bring some vision and some kind of sensor perception to bear so that we can find where to lay the welding bead the way the human operator does.

If I understand correctly, there are 850,000 people in the United States carrying torches. None of them like it. They want to upgrade in the company. It takes 4 to 5 months to train a welder and yet he wants out!

Assembly is a similar possibility. There are missing answers, but assembly represents the biggest labor density there is in industry. That's why the PUMA project started at General Motors. The Japanese have divided their early on activity into spot welding, arc welding, machine tool loading, assembly, and spray painting. They see rapid growths in each one of those fields, even though they believe that spot welding (and I agree with them) has reached a plateau. The market is not saturated, but it's not going to grow any more.

*Let's talk about Japan—and Japan vs. United States. Are they that much better in manufacturing than we are?*

Well, they certainly have advantages in manufacturing. First, I want to say they do not have a technological edge at all. They only have a fantastic ability to take an idea and make it work. Ideas that we've had, or European, and, of

**“...This is something that has just got to shake up manufacturing. They have such richness before them. Not just robotics, they have computer-aided design and manufacturing... it's tremendous today!”**



course, their own—wherever they got it from, and they make them go. Quality circle—that's a US invention, and they use it. Westinghouse goes over to Japan to see if they can do quality circles in their plants, and I think that it was an ex-Westinghouse consultant who came up with the concept. We have a robot design licensed to Kawasaki in Japan. They get an order from Toyota for 720—the biggest order we've ever had is for 120. The customer commits himself to 3 years production into the future. Do they know what they're going to do with those robots in the future? No, they don't know. They just say, "Dammit, we're going to use them. And you know what we're going to do? We're going to tell you six months before we want them which model we want and what articulations they should have." That's all the lead our licensee needs. Then the customer gets the damn robots for 60% of what American customers could buy them for. These guys come to me and cry, "Goddamn, look how cheap the Japanese robots are." I say, "Hey, you want to give me an order for 720, 25 a month for the next three years, and tell me even only six months ahead what the model is—and you've got it. You've got it 10-15% cheaper than Japanese prices."

*What are they doing right that we aren't doing?*

They certainly work on a management time scale which is much longer than ours. They're born out of college into their company, they're devoted to their company, and they expect to spend their lives in their company. They look to a longer range benefit from their activities. They don't have to worry about having an ROI of such and such two years from now, or else! So they can think at management levels in the longer term. The labor, for its part, is not worried about losing their jobs. They're saying that any innovation is great, that labor is for it. The company innovates, the company is more successful, labor gets bonuses—twice a year they get a bonus. The bonus is bigger if the business is successful. You've got both sides of the table interested in technological innovation, and interested in a longer term base of technological innovation. That is a crucial difference. And the management is from the bottom up. Decisions start from the bottom and finally get blessed at the top. The manager at the top tends to play all the strings to keep harmony. They have a word for it, "wah." When they have harmony, they can proceed. There's a lot of merit to that kind of thinking.

*And in the United States?*

I've got to admit I'm probably as big a culprit as any. If I

finally decide that this is the way to go, we do it by edict.

*It seems like to me that Japanese society is like a machine, very smooth once the engine starts to run, plodding, plodding, plodding. And they're very powerful because of their long-range attitudes, because they know they're going to be in business. They're a much older civilization. In the United States, in everything, we want a quick return on investment. We want things to happen right away, we want quick turn arounds, we want everything now. But traditionally we have had more innovation. Do you think that our type of system, although it seems chaotic and destructive in some cases, spawns more innovation and creativity?*

I'm not sure what spawns it. I think we are more creative. I think there are, unfortunately, some things happening in the United States that are stifling creativity. It is certainly reduced. The Japanese, I think, have almost outclassed us in patent applications in the United States. I've been on the President's commission for innovation and we're trying to study what the hell is going on. We're not innovating any more.

*When you say outclass us, do you mean quantitatively?*

Right, they're getting more patents. That's not a measure of very much, but it is a measure of the fact that these people are active, inventing. They never used to be. They started at the end of WWII making paper fans and crappy toys, then came up with an overall policy, "We're going to make quality, quality." They got that image, and they bought all the technology they could from someplace else, and they bought it cheap. Now they say there isn't any new technology out there anymore, we've got to do it ourselves—and they do it. They're coming out with technological innovations.

*What should we be doing to improve?*

The biggest thing I think will happen in this decade for advanced robotics won't happen in the robots themselves. It's going to happen in rationalizing the workplace. If you think back on when NC started, I remind you that almost every company in the world had separate letters and numbers and all kinds of systems to label their parts, and they were finally forced into putting numbers on those parts the computer could understand.

When I went to college you made a drawing with a line down the center of the paper and dimensioned everything off this line. Today, when you make a drawing you put a

dot in the corner, and why? Because you want to make it easy to program a tape for NC. It was a very hard fight to standardize that process so that it was easier to do numerical control. Slowly I'm seeing that the manufacturing world is structuring their workplace so that it's a friendly place for a robot to work. They'll be in a position where they're going to say, "I'm not going to throw everything into a box. I'm going to palletize it because a robot can palletize very easily. I'm going to store it on pallets; I'm going to bring it back on pallets, and another robot can find out exactly where it was palletized before.

If you look in a factory you find out that they have a certain scrap rate, and you'll see people worrying about

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**"...I'm not worried about technology. I think that the salvation of the world is in the hands of the technologists."**

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the fact that their scrap rate went from two and one half to three and a half percent. But consider that every time a person takes a part out of a machine tool and throws it in a tub, he's scrapped the orientation! Orientation is valuable, disorientation is scrap. In engineering terms, you've increased the entropy, and you have to pay for it someplace. You pay with labor, and, by the way, the labor that can take a disoriented part out of a tub needs only the mental equipment of an idiot. Unfortunately, we don't have all the technical answers to do it with a robot yet, so, we're looking at structuring the workplace and saying we're not going to lose orientation.

This is something that has just got to shake up manufacturing. They have such richness before them. Not just robotics, they have computer-aided design. If they design the damn thing right in the first place it's easy to get it together. They have computer-aided manufacturing, and if you don't have computer-aided manufacturing you cannot use group technology. There is already automated warehousing, but you can also have *oriented* automatic warehousing. They have automated inspection potential—it's tremendous today! If it's automatically inspected you can have robots selecting parts based on the results, and you can get around all the problems that exist in hard automation, where the only way you can get it to work is by reducing the tolerances on everything so that *all* parts go together. The human being doesn't need that, the robot doesn't need it if the inspection has given the robot the ability to understand.

All these things come together. You get benefits from all these other technologies that have nothing to do with robotics. If you're using group technology you're going to go from raw stock to finished goods so fast all your

inventory reduces. It's a tremendous benefit. You cannot do that unless the production control is on the computer. And when you do it you've played into the roboticist's hands. The whole thing is sitting there. The robot can transfer from machine to machine. The robot can understand that there are different production rates. The robot can buffer. The robot can anticipate the fact that we have down time for tool changes for accidents. If you use computer-aided design, you could find all the ways to design something so that it can be put together with a robot. If you somehow take away from the designers their god-like role on function and appearance, and get them to listen to the people who make it, it would be ideal.

Automobile assembly is very simple, if you don't do sequential welding. On a lot of cars today, they keep welding little pieces of metal on all the way down the line. If you stick all the metal together in the first place and design it that way, the robot'll finish the whole job, but if you're going to put little pieces of metal on that car all the way down the line, you'll have to use people.

We did a design for the assembly of the governor assembly for a transmission. With the original parts, we did it one and a half times as fast as a human being. It was hell. Among the recommendations we made were nine design changes—none of which would have cost anything, not a thing. It's enough to tell the designer that the changes do not influence function, that if they do it this way we can put it together easily. I can even go beyond that. It would even be a lot easier for *manual* assembly if they made those design changes! This is the sort of thing that is going to happen. It's going to flow back from the factory floor, *rationalizing* the workplace.

*So in a sense you're just making better use of existing technology and improving methodology?*

Well, the technologies which I just mentioned are really a forefront, just like robotics. Computer-aided design is really brand new, but remember all the reports about how everything was going to be NC by now? Well it sure isn't yet, and there's a lot of other things that can be done in the layout of plants and so forth.

The things that the robot still needs and doesn't have are eyesight and tactile sense. They are each very, very broad subjects in themselves. I'm not talking about replicating the combination of the human eye and the human brain. That's high intelligence. That has not been replicated. On the other hand, there are already seeded computer programs in chess. Chess players are seeded, like tennis players, and there are seeded programs. That highly stylized information handling that we have in robots

(if you want to call computers robots) makes them smarter than some people, but only in very specialized ways.

*We don't have to copy humans anyway.*

Certainly not, and there are a lot of advantages for a robot designer. For example, you don't have to put the eye in the head, you can put the eye in the overhead or in the palm of the hand, which may be useful.

Machines in most cases shouldn't be designed like people. If you want to find one real distinction between a human being or animal life and machinery, it's a bearing. All animal life is unable to have continuously rotating members. Now for us, flying depends upon continuously rotating members. We did an awful lot of flapping in our early years before it dawned on us that a continuously rotating member would be the way we could get propulsion in the air. Now, when we do investment casting, we have one big advantage over a human being. We can put a continuously rotating member at the end of the robot's arm. That's the kind of thing I mean. You must take advantage of what the mechanical world offers when you try to accomplish what the human being does without fully replicating him. That's what I plan to do when I build my household robot. People laugh about it when I tell them, but I intend to have a robot in my office in the next year and a half. He will grow in agility and mental capability as time permits. I'm going to be able to have a robot come out of a closet and go to the galley to serve my guests.

*You mean a mobile machine?*

Yes, and it will do what it needs to make coffee and other simple things, maybe convenience foods. I will add on to it. It will have voice communication. If you look at voice communication the art is growing so fast—we've already got good synthesis. There's reasonable recognition, with some problems in it, but the work that IBM, for example, is doing in voice recognition is fabulous. Ultimately, you'll go into a home which will have a maid, and the maid will be a robot. The robot will be a butler as well. But you will have to design that house to be compatible with robot life as well as human life.

*It seems in a plant we have a similar problem. A robot doesn't like to work in an unintelligent world. We can do it because we have such a high degree of intelligence, but it's not right to ask a robot to assume all the burden of intelligence as we do. It needs to work with other*

*intelligent devices, and not have all the burden be on the poor robot's back.*

That's where Jim Albus's hierarchy idea comes in. You have different levels of intelligence, you communicate, you distribute the intelligence down to the robot. To put this into perspective, remember the film, "2001," and HAL? You never saw HAL. To kill him they had to chop away; he had permeated the entire vessel, but you didn't see him. Like a spirit, almost. That, by the way, is what is going to make the Air Force ICAM program. When we distribute the robotic intelligence through the airframe plant, robotic intelligence that can read the database that is the airplane, communicate this with all the elements of the factory and make them do their thing, then they will make the airplane like they designed the airplane. Now they make the airplane like they built farm machinery in 1910.

The stand alone robot is an interesting beast, too. If you go to "Star Wars," you see R2D2 and C3PO, and you can relate to them. There's room for that creature in the factory, in the home, and in service industries. One of my dividends from being in robotics is having a vice president from McDonald's take me into one of his stores and buy me a Big Mac, because he said he'd like to think about having robots in the kitchen. It's great—except we couldn't do it just yet. We don't have the sensory perception to react to that environment. It's a highly stylized environment, and the turnover in labor is tremendous! They can get some kid to learn how to run that shop in 20 minutes. We will do it eventually—we'll be able to take on some of these stylized jobs.

*You seem to like being well-known and speaking for the industry.*

Oh, yes. I think, by the way, you'll find that most entrepreneurial people who have succeeded in business have too. That's just one other quality that had to be there. If you're not a super salesman, the idea that you're promoting is going to die, or at least it will be in limbo until somebody else picks it up and starts to sell it. I think that Devol and I were definitely complementary in that regard. He had good ideas, but they were unstructured. I think because I was a physicist I was able to structure the ideas. But beyond that I think that I could communicate the vitality of the idea. That's the contribution I was making at the time.

*Now you have the award, the Joseph F. Engelberger*

award.

Which I've divorced myself from in the sense that I refuse to be responsible for the choice of the recipient. You can be sure that I wasn't responsible when you note that the last three prizes went to executives from the competition! Personally, I consider all of them deserving, but I would have picked more academics in the field. To get around that I have suggested that the reward should be three awards, all carrying the same honorarium (\$1,000), with all recipients getting the medal. There are so many people that should be honored that we're not, because there are different classes of contributions that we aren't covering. There are people that make a technical contribution to the art. There are also people who make contributions in the applications area who find the ways to use this technology, who are very important to the field. There are people in the academic community who sponsor the dissemination of the art. There may be other classes as well. At the next conference and symposium there will be three awards given. The Robot Institute of America will choose the recipients.

*That leads into the part of being the "Father of Robotics."*

Well, you know, without being falsely immodest, I think I can claim the accolade. Robotics as an industrial field didn't exist before, it does exist now, and whatever technical contributions were made, I sure promoted it and did the institutional job I talked about before. Furthermore, I still do it today. I doubt very much if my competitors would be very much distressed if I were representing the industry and giving a lecture about what robotics is all about. I have slides on all of their products. I'd say, here's the classes of robots and applications, and then if I derived the experience part of the lecture from Unimation, it wouldn't be disproportionate to the amount of experience Unimation has.

So my position tends to be one that is institutional. I go to Washington and represent our technology regarding trade agreements with foreign countries—and that's what a trade association should do, by the way. Defend the trade. Should we be able to sell our technology to Russia, for example? There's a whole bunch of naive people in Washington who don't understand how smart the people are over there. They don't understand they will get the same damn thing from Germany anyway. Why not be commercially sound and sell the product? But, in any event, that is the job for the spokesman for the industry, and I think I can aspire to the role of elder statesman.

*Is that of great personal satisfaction to you?*

Yes, it is. I started a business which today happens to be more profitable and bigger than Unimation, Consolidated Controls. I started Energy Research Corporation, and that's a good business. But in Unimation I've started an industry. That's a different thing. How many people in their life through luck happen to get in the right position at the right time to do something with such a profound impact—without going into politics? That's got to be very satisfying.

*I believe it was Bronowski who said that in mathematics, most of the important contributions were made by people in their twenties.*

Mathematics often has very young contributors. Musicians peak very young, with the possible exception of Handel, who did the Messiah when he was close to 80, I believe. It's an interesting thing. Writers peak out around 48—apparently you need an awful lot of experience. For making money, by the way, the optimum age is 66. In mathematics, definitely, fundamental contributions are accomplished by very young people.

*Let's talk about the hobbyists. What kind of contributions could the kids at home with their Apples and their TRS-80s do, if any, to robotics or the advancement of the art? What can they do to get on the road?*

Oh, they can have a whole lot of fun. The problem is if you have a home computer and you're playing around, nothing physically is happening. After you've got all the damn charts on the screen, and have done all the video excitement, nothing is happening! But if you have some sort of rudimentary robot arm it will do things! Take one simple thing, chess. Instead of having you move the pieces around a board because the program tells you to, the robot can sit over there, connected to the same program, and it will move the pieces itself. Any hobby arm on the market could do it. Microbot, which was written up in your magazine, is an elegant little machine.

The chances of some very bright person coming up with a serendipitous discovery has got to be good. They're going to come up with something! On the other hand, I would say that academics with impressive credentials have been severely handicapped by playing with robot arms that are ridiculously weak and have a low natural frequency, and so forth. Their ability to get funds from industrialists is very low, because an industrialist comes in with blinders on. He's not going to look beyond what he sees. He won't extrapolate and say, geez, there's something beyond all

that. I don't know what the hobbyists, the academics, and all will do. I think everyone has a chance to make a contribution. There's a lot of new stars discovered every year!

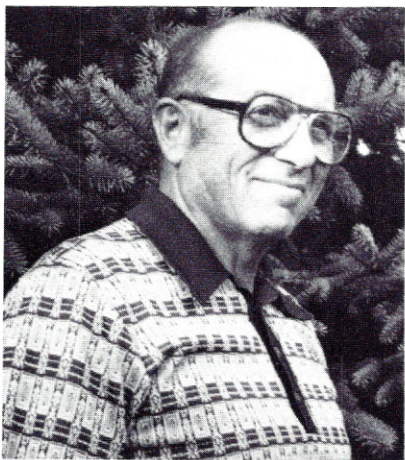
*' What kind of contribution has science fiction made to the art of robotics, if it is an art, which I'm not sure if it is.*

Well, I consider it very important. Chances are if I hadn't been a fan of science fiction, I wouldn't even have reacted positively to an eccentric who met me at a cocktail party and started talking about robots. Through that background, coupled with being a physicist and having some experience in high technology, that guy's idea happened to land in fertile ground. I was there, I was ready. Science fiction was a very big part of being ready.

*In RUR, the scientist built the perfect robot. Everything was great, they did a great job until the sociologists came in. Remember, the girl that wanted to make them more human.*

Except that if you recall there was just a tinge of hope at the end as they made it more human, and two of them left hand in hand and love was reborn. The new Adam and Eve. That's really worth remembering because *RUR* is always remembered as being the exponent of the malevolent robot. In contrast, Asimov should be remembered as the proponent of the benevolent robot. Now you've got these two diverse paths, and they sometimes meet. You have good and evil robots in "Star Wars."

*The Asimov robots were all good.*



Yes, their circuits required it. They couldn't be anything else but. That and the "three laws" were built in.

*I thought RUR as a very well written play. It's mentioned in every robot article, but I don't know anyone who's actually read it.*

Well, I've read it. It hasn't been done on stage recently, but it was done by college groups for quite awhile. It's entirely possible it could enjoy a revival.

*I hope so. We have Asimov on one end and we have Capek on the other. In between we have Jack Williamson, who wrote "With Folded Hands." That's where the perfect robot is built, little black sleek machines. They protect man from doing anything wrong—there's no evil, no war, no stress, no strain, no cigarettes, nothing. And man ends up trying to get rid of this machine that's so beneficial that he can't stand it anymore. That's one of the classic robot books.*

It's the same with Al Capp's Shmoo. That's why in the sociological sense I've always thought the robot has an interesting place to fill. It's something like the place of a Shmoo. We have a very long history in human relationships that includes human slavery. The very idea, today in the United States, of any class of people being inferior, even though they patently are, must never be spoken of. On the other hand, a robot class would be patently inferior, and also would fulfill a certain sociological gap—you are allowed to look down on a robot.

*Machines are bigger, faster, and stronger than a human is. Computers can play chess, and are starting to approach high levels of artificial intelligence. No chance of them surpassing man?*

No chance? I wouldn't say that. I think that it is very difficult to conclude that they will, because someone's got to be motivated to do it. The thing that's frightening to most people is that there are certain kinds of computations at which the robot already surpasses man. I don't think there will be something like what occurs in many science fiction stories, where robots are slyly whispering to each other and saying, "Don't let on, Charlie, but we've got them. Now let them keep building us because at the right moment we're going to take these bastards."

*Or obviously, imagine robots building robots, and building in fake off switches. We think that if any machine*

*(continued page 38)*

# ROBOTS V-DEARBORN 1980

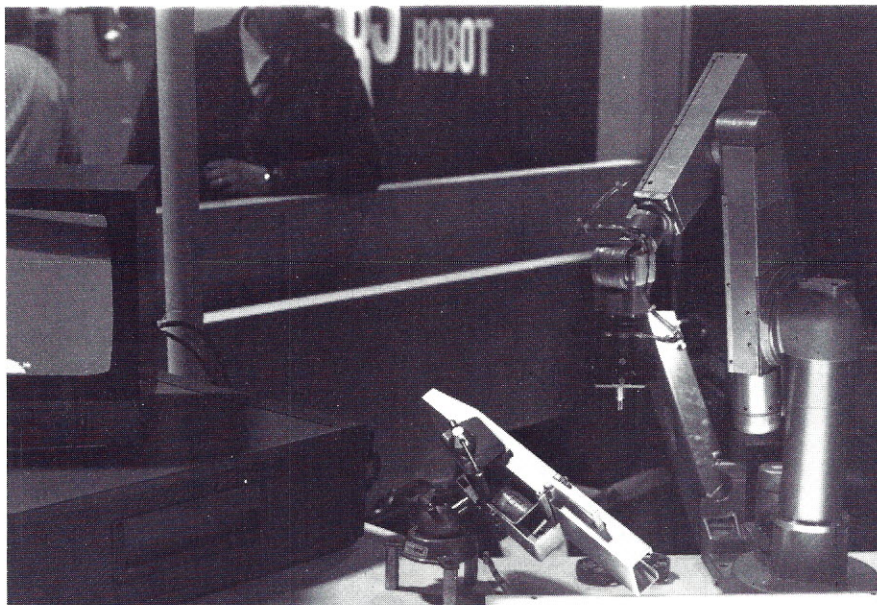
by  
William A. Gruver  
Logistics Technology Inc.  
Torrance, California

New developments in robot applications and technology were the highlights of ROBOTS V Conference and Exposition held at the Hyatt Regency Hotel in Dearborn, Michigan, October 28-30, 1980. Cosponsored by the Society of Manufacturing Engineers (SME), the Robot Institute of America (RIA), and Robotics International (RI), SME's newly formed organization for individuals in the field, this three day event topped all previous records for attendance and participation. In addition to the exhibition, which featured the latest developments in robot products and services, several technical presentations were organized with more than 1,000 people in attendance at each.

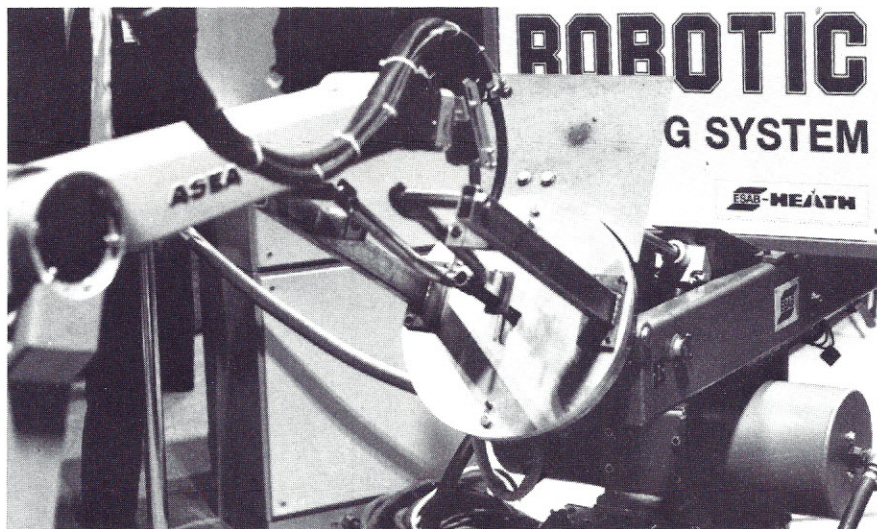
A news conference held on the first day of the event gave members of the national press and media opportunities to question a panel of leaders from the robot industry including James K. Bakken and John DiPonio of Ford, Unimation's Joseph F. Engelberger, and John A. Fulmer of Cincinnati Milacron. A broad range of issues were discussed, from vision and tactile sensing to the effects of robots on employment and the possibility of a household robot by 1985. As may be expected, there was considerable disagreement on the latter question.

Another news conference held on the second day featured the unveiling of a number of new products from one of the latest entrées into the high technology systems area of robotics, Automatix Incorporated. The Autovision System by Automatix (See *Robotics Age*, Fall 1980, pp 22-28) was demonstrated, along with a new arc welding system. The president of the corporation, Phillippe Villers, described the goals and progress of the company in developing complete robot systems that incorporate the latest technology in visual sensing.

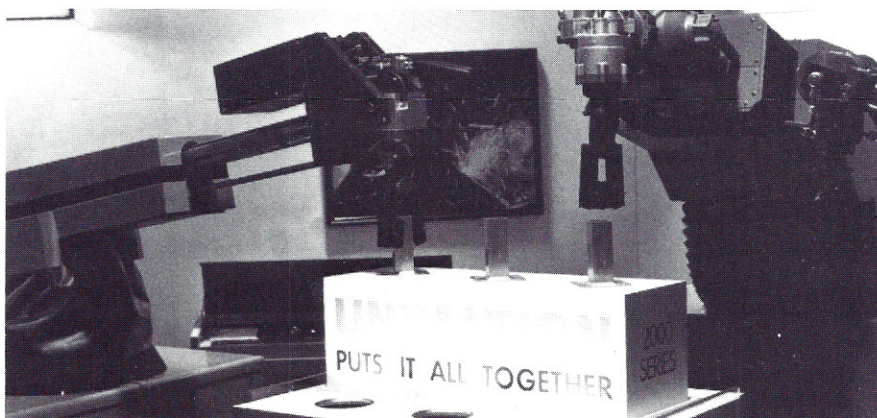
A total of 29 technical presentations in seven sessions focused on implementation, application, and technology breakthroughs in industrial robots. The titles of these papers and the authors are listed at the end of this report. Three applications sessions explained new uses in plasma coating, forging, die casting and press loading, and a case history concerned with aspects of the automated factory. Two technology sessions described advanced concepts, including adaptive control, visual and tactile sensing, and other intelligence factors characterizing new "high technology robot systems." In addition, an implementation session examined the management approach to robotics for evaluation and applications feasibility. ®



The versatility of robot vision was emphasized in a demonstration by Machine Intelligence Corp. Parts placed at random on the viewing stage of the MIC system were located and identified. The coordinates were then passed to the controller of a Unimate 250 manipulator which grasped the part and placed it in the chute to repeat the cycle.



The Swedish firm ESAB demonstrated their robot welding system, which features simultaneous control of the ASEA robot and a programmable weld positioner.

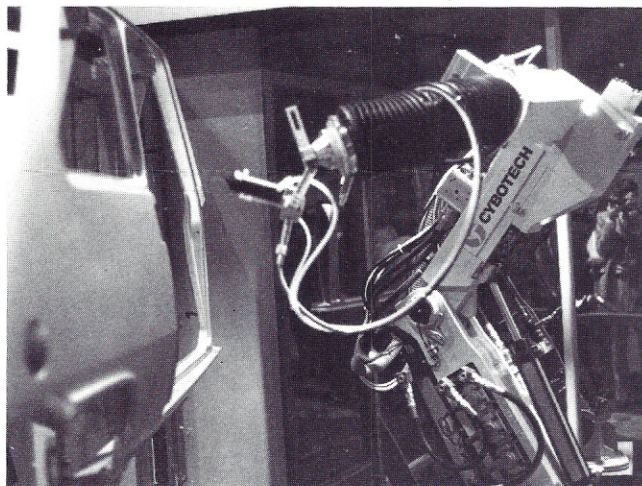


At the Unimation booth, Model 2000 (left) and 4000 (right) robots worked together to spell their company's name.

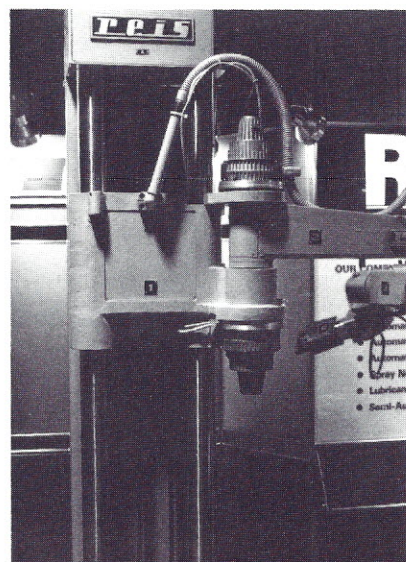
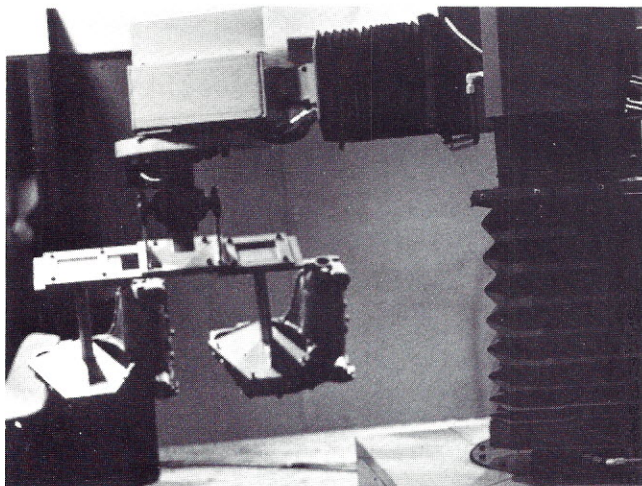
*In a lighter vein, Thermwood's Series 6 spray-painting robot seemed to try its hand at something different.*



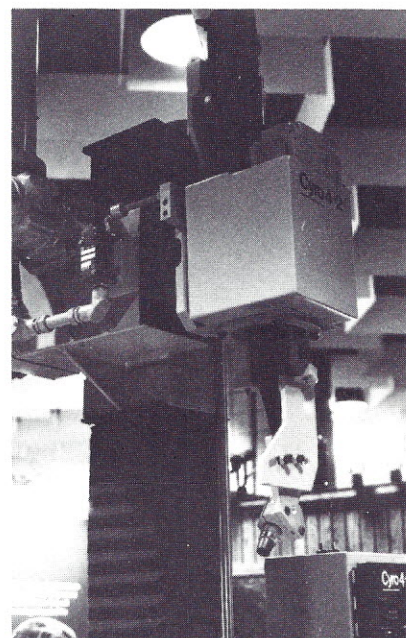
*The new Cybotech robot was demonstrated in a spot welding application.*



*A PRAB Versatran servo-controlled robot demonstrated high speed movement carrying a heavy casting.*



*A new entry from W. Germany is the Model 1215 from Reis Machines, a 6-axis electrically driven servo manipulator.*



*Advanced Robotics Corp.'s new "Cyro" welding robot is a 4 to 6 axis machine whose movements may be coordinated with those of its 1 to 3 axis weld positioner.*

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Entries in the **Robotics Industry Directory** are provided free of charge to manufacturers and distributors of robots, robot subsystems, and components; to research organizations; and to firms offering related services such as consulting, engineering, and system integration. To confirm your organization's listing, please contact:

Editor

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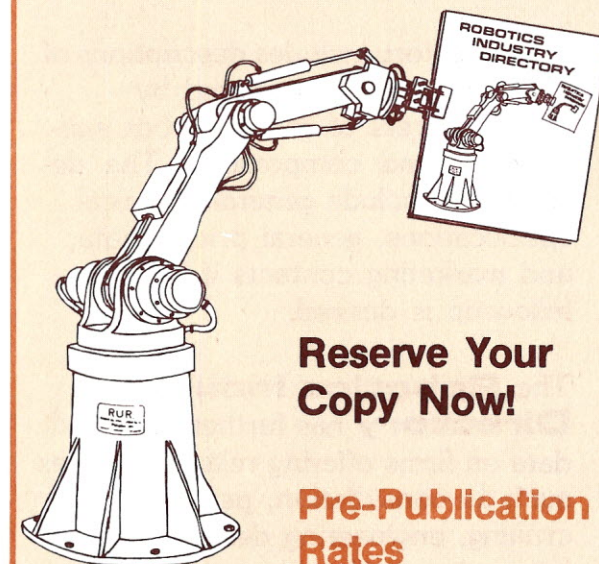
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Another section will address specialized applications.

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The technical staff of **Robotics Age** magazine will review this material for editorial accuracy, ensuring the most complete, up-to-date information possible.

The **Robotics Industry Directory** will include a number of reader service cards which will provide service during all of 1981. At any time during the year that additional information is desired for a particular project or research interest, a new card may be submitted indicating all of the relevant products and firms.

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## IMPORTANT ANNOUNCEMENTS

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With this issue **Robotics Age** becomes bimonthly. This issue, which would have been our Winter 1980/1981 issue becomes instead our Jan/Feb 1981 issue and begins a new era in the history of **Robotics Age Magazine**. With increased frequency, of course, comes a subscription price increase and the additional revenue will enable us to add staff (see announcement on opposite side) so that **Robotics Age** will be better than ever before in 1981.

Please note that current one year (4 issue) and two year (8 issue) subscriptions will not be extended on a calendar basis. With the new bimonthly frequency, current subscriptions will be converted based on the number of issues remaining. To ease the transition to bimonthly we are providing, to current subscribers only, a limited time subscription extension plan. You may add as many issues as you like to your subscription for only \$2.25, a 75¢ per issue savings off our usual cover price, and a significant savings off our new subscription rates listed below. Payment must accompany your order.

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The Autovision™ System  
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## Editorial Staff Increases

Joel M. Wilf joins *Robotics Age* as Managing Editor. Mr. Wilf, the author of numerous articles on robotics and related technical disciplines, was a member of the team that developed the robot spacecraft and lander for NASA's Viking Mars Mission. While with NASA, Joel also conducted research in robot vision and sensory control methods before leaving in 1979 to pursue a career in science and technical writing.

"Joel brings to *Robotics Age* an excellent background of achievement in a variety of fields and is a valuable addition to the editorial staff."—Alan M. Thompson, Editorial Director

**Please note** that due to our change to bimonthly this issue is called Vol. 3, No. 1, Jan/Feb 1981 instead of Vol. 2, No. 4, Winter 1980/81. **This in no way effects your subscription.** If you have a 1 year subscription you will receive 4 issues (2 years—8 issues).

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## PRODUCT NO.

## PRODUCT

- |    |  |
|----|--|
| 1  | Cincinnati Milacron: T <sup>3</sup> robot, p. 42 |
| 2  | Thermwood: Series 3 robot, p. 42                 |
| 3  | Automatix: Robot Welder, p. 43                   |
| 4  | Hobart: Robot Welder, p. 43                      |
| 5  | Spatial Data: Video System, p. 43                |
| 6  | PMK Assoc.: Chess Robot, p. 44                   |
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| 11 | Cromemco: I/O Processor, p. 45                   |
| 12 | Teslaco: Cuk Converter, p. 45                    |
| 13 | Stanford U.: HPP Brochure, p. 46                 |
| 14 | Byte Books: p. 46                                |
| 15 | PMK Assoc., Chess Robot,<br>inside front cover   |
| 16 | Lamar Instruments:<br>SUPERKIM SBC, p. 52        |
| 17 | Hobby Robotics: Robot Kits,<br>inside back cover |
| 18 | Robotics Industry Directory,<br>back cover       |

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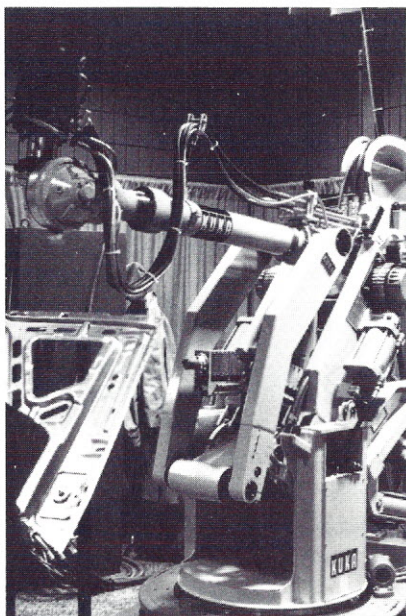
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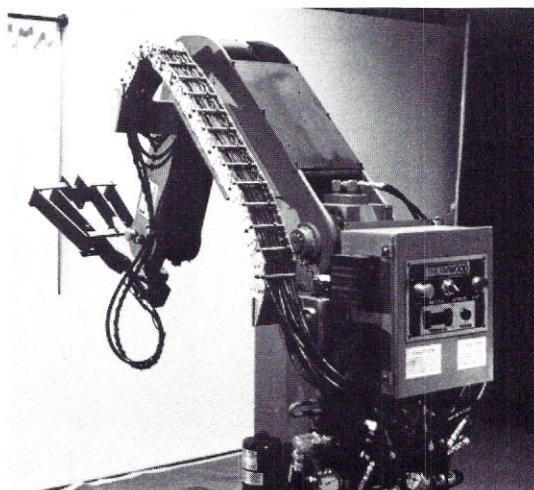
## READERS ADDRESS THE EDITOR

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	ARTICLE NO.	POOR	GOOD	EXCELLENT
Robot Arm	1	0	1	2
Engelberger	2	0	1	2
Dearborn '80	3	0	1	2
Opto "Whiskers"	4	0	1	2
Toy Design	5	0	1	2



*The West German manufacturer Kuka unveiled its new robot at the show. It was demonstrated performing simulated spot welds.*



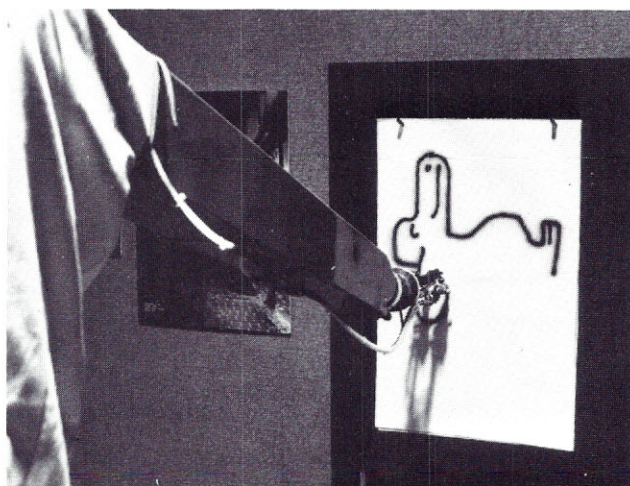
*Thermwood's new Series 3 servo-controlled, general purpose robot.*



*The Unimate PUMA robot demonstrated its continuous-path capability by tracking a cloverleaf template.*



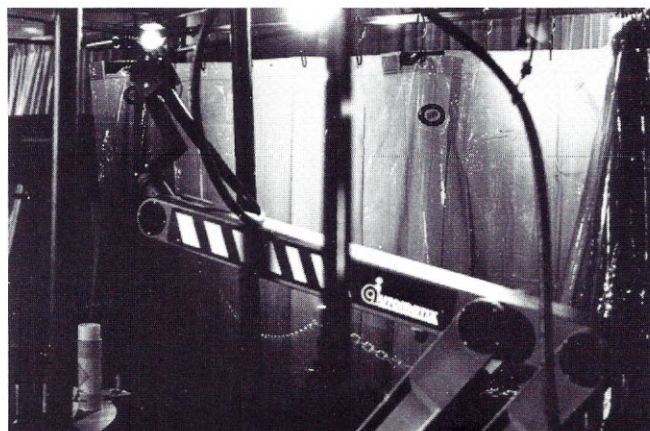
*The "Maker" robot, newly introduced by US Robotics, is a low-cost, 5-axis electrically driven servod robot.*



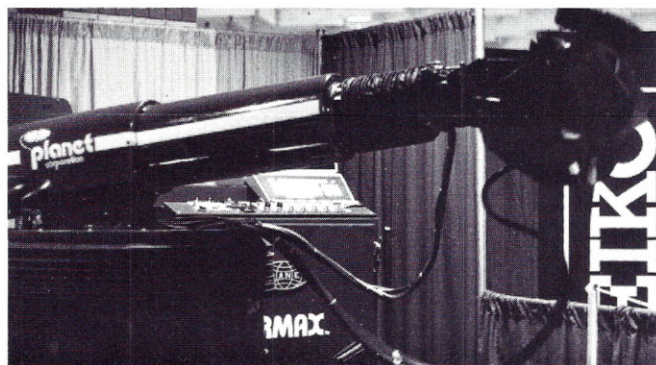
*The DeVilbiss-Trallfa robot demonstrated its painting talents in a rendering of one of its favorite cartoon characters.*



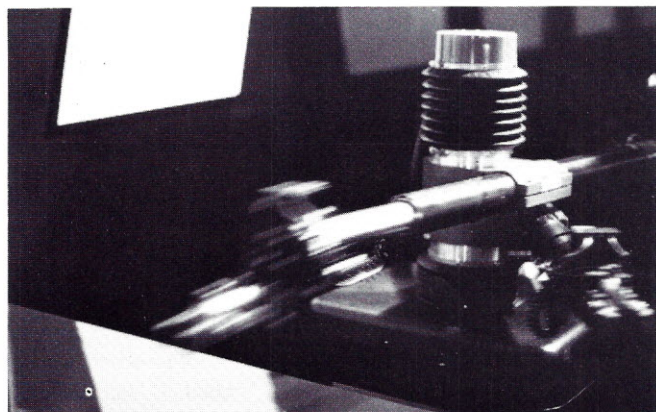
Cincinnati Milacron's "T3R3" robot features the company's new 3-roll wrist. (see New Products announcement this issue.)



Automatix, Inc. presented its own entry in the robot market—a welding system that performed actual spot welds at the show. The plastic curtain protected onlookers from the sparks.



Planet Corp. demonstrated their new "Armax" robot, a mechanical-stop machine with 2 to 7 axes.



One of the new robot products demonstrated by Automatix, Inc. was a dual fixed-stop pneumatically driven arm configuration.

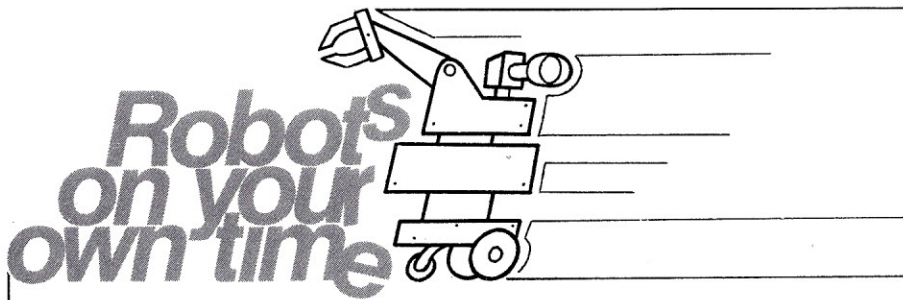


C. Milacron's familiar T<sup>3</sup> robot was shown in a typical work setting.

## Technical Presentations and Papers

- [1] Jack Lane, General Motors Institute, "What are Robots?"
- [2] Sandra Pfister, Unimation, Inc., "A Look at Robotics International of SME."
- [3] Mike Skidmore, Cincinnati Milacron, "The International Market for Robots and Future Trends."
- [4] Neale W. Clapp, Block Petrella Assoc., "Management Resistance to Industrial Robots."
- [5] J.A. Behuniak, General Electric Co., "Planning and Implementation of Robot Projects."
- [6] Brian W. Pollard, Unimation, Inc., "RAM for Robots."
- [7] D.T. Cousineau, General Electric Co., "Robots are Easy...It's Everything Else That's Hard."
- [8] James K. Bakken, Ford Motor Co., "Productivity, America's Favorite Compensation." (keynote address)
- [9] William J. Higgins, Williams and Higgins Industrial Sales, Inc., "Machine Loading Robot Incorporating Coordinated Hand to Hand Part Transfer."
- [10] Kenneth N. Shaley and Francis J. Donohoe, B-J Associates, "Programmable Robot, Rotary Table System."
- [11] Dan Fitzpatrick, Prab Conveyors, Inc., "Productivity through the use of a Two-Armed Robot."
- [12] W.R. Riche and J.G. Boerger, Cummins Engine Co., "Unimate Application at Cummins Engine Company."
- [13] Thomas Wheatley, National Bureau of Standards, "Proceedings of NBS/Air Force ICAM Workshop on Robot Interfaces." (panel discussion)
- [14] Robert H. Green, Prab Conveyors, Inc., "Application Analysis—Comparing Motion Coordinate Systems in Industrial Robots."
- [15] Moshe Frank, Cincinnati Milacron, "A Three Roll Wrist Robot."
- [16] P.F. Rogers, Unimation, Inc., "The PUMA Robot—A Vision Application."
- [17] Charles A. Rosen and Gerald J. Gleason, Machine Intelligence Corp., "Evaluation of Performance of Machine Vision Systems."
- [18] Leon D. Harmon, Case Western Reserve University, "Touch Sensing Technology: A Review."
- [19] Edward Kroeger, Ford Motor Co., "Robotics: The Final Step in Transfer Line Automation."
- [20] John Saladino, General Electric Co., "Upset Forging With Industrial Robots."
- [21] Thomas Blunt, General Electric Co., "Low Technology Robot Press Loading."
- [22] D. Woern, Kuka Welding Systems and Robots, "Safety Equipment for Industrial Robots."
- [23] William A. Gruver and Robert M. Canady, Logistics Technology International, Ltd., "Modern Technology for Computer Control and Logistics Support of Robotic Systems."
- [24] John Hayes, Shelby Die Casting, "Reliability and Performance of Industrial Robots in a Die Casting Operation."
- [25] Robert G. Fish, GMC/Hydra-Matic Div., "Robot Utilization in Automatic Handling Systems."
- [26] William J. Higgins, William and Higgins Industrial Sales, Inc., "An Automated Factory for Today."
- [27] William M. Cameron, University of British Columbia, "Immediate Applications for Industrial Robots in the Nuclear Industries."
- [28] Richard C. Movich, Lockheed-California Co., "Robotic Drilling and Riveting Using Computer Vision for Position Servo Controls and Inspection."
- [29] John M. Vranish, Naval Surface Weapons Center, "Robotic Deriveter, System Concept."

Requests for copies of technical papers presented at ROBOTS V should be directed to the Society of Manufacturing Engineers, One SME Drive, Dearborn, Michigan 48128, (313) 271-1500.



by  
Martin Bradley Weinstein

# OPTO "WHISKERS" for a Mobile Robot

Suggestions for improvement on a basic optoelectronic proximity sensor

In my research of obstacle detection schemes, the most obvious common requirement that emerged is the need for an inexpensive circuit that could simply say "there's something here." Precise descriptions of the object being detected, its absolute or relative position and other specifics concerning it are of interest, of course, but the first priority is to detect its presence.

Some of the primitive mechanisms that have appeared in published articles rely on actual mechanical contact between the mechanism and the obstacle. Bumpers that actuate microswitches, pressure-sensitive ribbon switches and stiff wires attached to microswitch actuator levers are among the several forms of mechanical contact-sensing switches that have been tried, all with some success.

But this is analogous to wending our ways about with blindfolds on, requiring that we touch a wall or tree or bit of furniture in order to make any progress. This is because the inherent limitation of contacting obstacle detectors (and of our finger, when we're blindfolded) is that they can only tell us where things *are*; it would be much to our advantage if we could design them to also tell us where things *aren't*.

So consider, if you will, a theoretical system of precisely

positioned "wires" of no mass and no substance, but with the ability of signalling whether or not they are being intercepted by any object. If a biological analogy will help, you might consider the whiskers of a cat. With enough of these "whiskers," our mechanism could be perfectly aware of the space surrounding it—at least in terms of free paths and obstacles within the sensor's range.

There are ways to achieve this type of device in practice, including radar and SODAR\* systems and reflective optical systems. The high cost of the two former approaches tends to obviate them in favor of the latter where a large number of such sensors are anticipated.

## Some Problems

If the entire world were dark and all obstacles were vertical cylindrical mirrors, all we would need to do is shine a single, omnidirectional light and rotationally scan for

---

\*SOund Direction And Ranging, using a directional ultrasonic range measurement circuit.

reflections. But there are other lights to cope with in the real world, requiring that we somehow "label" our light by giving it some special characteristic not likely to be duplicated in the environment the mechanism must negotiate.

Another difficulty is that most optical detectors can be swamped by ambient light within their sensitivity range, spectrally speaking. Still another is that the spreading of the outgoing beam and the off-axis sensitivity of the detector combine to both waste power and limit the resolution of the "whisker."

And another problem—indeed, one we've already touched upon—is that we must try to solve all these problems inexpensively.

Fortunately, we're not the first to face these problems. In industry, for example, both beam-break and reflective systems (including both reflective beam-break and reflective beam-make designs) have been used in the positioning of machinery and the counting of parts.

### *Enter the PLL*

In a search for a better answer to problems associated with using light emitters and detectors in positioning applications, Richard Oliver of Centralab Electronics, West Lafayette, Indiana, developed a simple circuit based on the NE567 phase-locked loop tone decoder IC. [1] His circuit, with only minor modifications, appears in Figure 1.

In this circuit, the pin 6 output of the current-controlled oscillator (a  $1V_{PP}$  exponential triangle waveform with an average DC level of half the supply voltage) drives IC2, an ordinary 741 op amp. The 741 squares up this waveform and drives Q1, an inverting power driver which turns on D1 (an infrared-emitting diode) in implicit sync with the PLL. When Q2, a phototransistor, sees the output of D1 and provides its signal to the input of IC1 (the NE567), the loop locks and turns on its output, pin 8, which lights indicator LED D2.

A breadboard of this circuit with the components indicated is capable of detecting a human hand at about 2½ inches, a piece of white paper at about 4 inches.

It should be noted that this performance is without the benefit of optics external to the lens-packaged infrared-emitting diode and lens-packaged phototransistor, and with all power provided by a standard 216-type 9 Volt "transistor" battery.

Obviously, this level of performance is unsuitable for the kind of "whisker" function we're considering. Both the output power of the emitter and the sensitivity of the

detector are going to have to be greatly improved.

While far from ideal, the circuit shown in Figure 2 represents an impressive first effort. As shown (and again, without external optics and using only a common 9 Volt battery), this circuit can detect a human hand at about 2 feet, a piece of white paper at about 3 feet. For some applications, this may prove adequate; for others, simple lenses may adequately improve performance. In any case, further experimentation (both by readers and the author) is strongly suggested.

### **Improving Radiated Power**

The XC881 emitter used in Figure 1 is rated for about 3 mW at drive currents near 1 Ampere; unfortunately, junction heating would quickly destroy the device if it were run continuously at this level, or even at the 50% duty cycle of this circuit. The manufacturer recommends limiting pulse duration to 100 microseconds at a 10 pps rate.

Of course, the battery is another limiting factor here, since these batteries cannot sustain a current requirement beyond a few hundred milliAmps for more than a short period.

Another problem is that the switching transistor must itself be capable of delivering this level of current drive (and pulse response) without unduly loading the driving circuit.

Fortunately, we are at a very good time in the developing state of the art of manufacturing infrared emitters. The Xciton SC-88-PC "Super High Output Infrared Emitter" used here, for example, is rated at 10.5 mW total radiant output power at 100 mA drive, or a peak pulse current of 3.0 Amps (10  $\mu$ sec, 100 Hz) can deliver over 200 milliWatts. [2] Furthermore, the lens on its TO-46 style package is designed to provide a 15° angle between half power intensity points. This Xciton device is not the only one available with these capabilities, although Xciton prices bear watching because of the company's commitment to producing products specifically for high volume markets (and thus tends to quickly feel the price-reducing efficiencies of high-volume production).

AEG-Telefunken, for example, offers type CQX-19, rated 500 mW at 10 Amps drive (20  $\mu$ sec, 1500 pps) and a 40° half-intensity angle. [3] Similar devices are also available from RCA [4]; Spectronics [5]; and Texas Instruments [6].

The pulsed operation helps make battery operation more reasonable, too, by greatly reducing the average current requirement on the battery. The 100  $\mu$ F capacitor

across the supply provides enough charge storage to handle this requirement while also providing ample decoupling ballast to help keep pulse current requirements from appearing in the receiver; in addition,  $0.01\mu\text{F}$  bypass capacitors are sprinkled generously throughout the circuit.

The op amp squaring buffer of Figure 1 is duplicated, with a slight increase in gain. This drives a CD4047, configured as a monostable multivibrator with a very narrow pulse width, well under  $1\mu\text{sec}$ . The output of the 4047 drives a 2N2222 and TIP3055 pair of NPN transistors in a Darlington configuration, which in turn drive the emitter.

An effort was made to use exclusively off-the-shelf, easily-available components, which are both inexpensive to obtain and not terribly critical in terms of current, voltage or thermal operation.

### Improving Detector Sensitivity

The BPX25 phototransistor [7], a Ferranti part, is not

remarkable for any unusual sensitivity (typically  $55\mu\text{A}/\text{ft}^2$  minimum sensitivity rating), but does offer an advantageously narrow  $3.5^\circ$  half-sensitivity/response acceptance angle. The package is a metal TO-18 with a glass lens, nearly identical to that of the emitter.

The first area where improvements were ventured is the emitter bias resistor. A substantial range improvement resulted from raising its value to  $220\text{K}$  (from  $68\text{K}$ ); further increases in this resistance with this particular device resulted in insufficient signal and no output from the 567. Also, the coupling capacitor was raised in value to  $0.022\mu\text{F}$  to help lengthen the time constant of the input circuit and hopefully let a little additional energy through while still rejecting slow changes in detected energy. This input circuit, when breadboarded, exhibited no tendency to swamp (saturate) with high ambient light levels.

The only other modification—again, a significant one—was to add a  $470\text{K}$  resistor to ground at pin 1 of the 567; this came straight out of the manufacturer's device data as a suggested means of improving the input sensitivity of the 567.

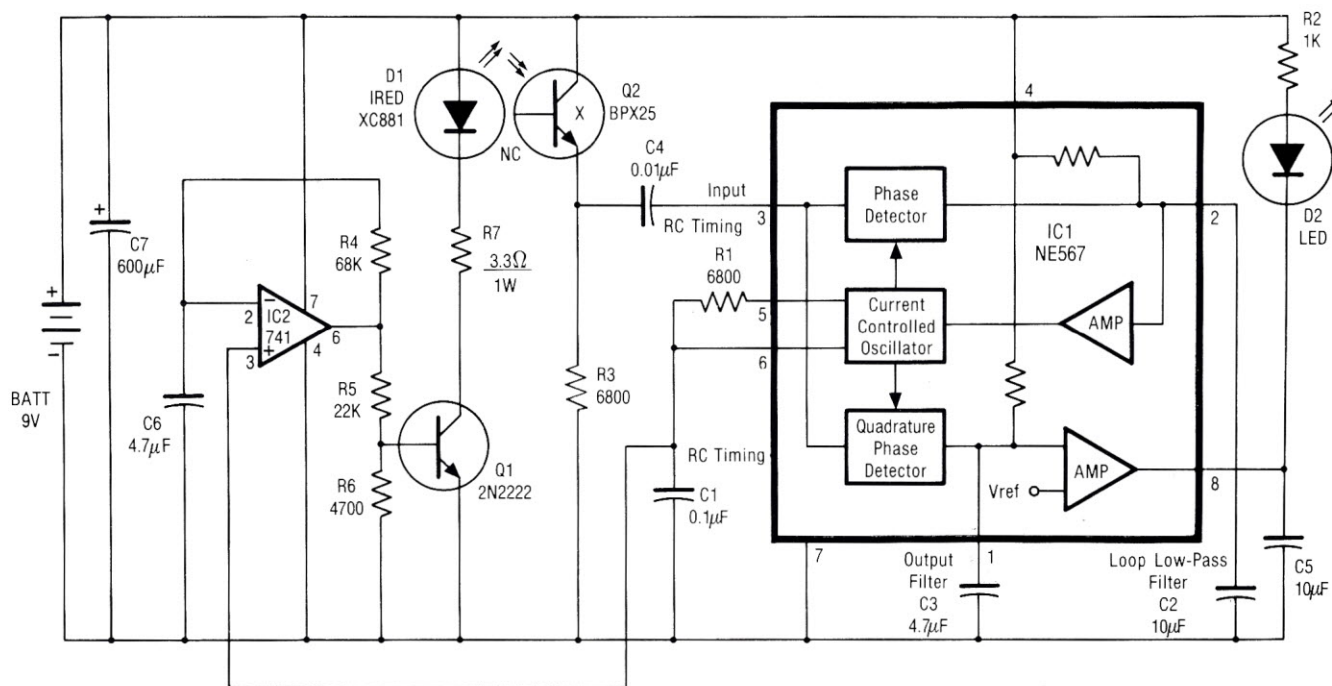


Figure 1. Modulated optoelectronic proximity detector, adapted with only minor revisions from 1975 EDN article [1] (see text). As shown, circuit responds to human hand at  $2\frac{1}{2}$  inches, white paper at 4 inches.

Signal from IC tone decoder PLL oscillator drives emitter through op amp and transistor; detected reflection triggers response from IC. This scheme offers very high immunity to ambient light.

## Isolating the Output. And Notes on Further Improvements

Since the absolute maximum supply voltage that the 567 is rated for is 10 Volts and the specific system to which the "whisker" will be added may operate at some other voltage, a standard 4N36 optoisolator was added to the output of the 567 to provide a more general interface. A red LED indicator is included here for ease of observation during experimentation.

Obviously, from the notes here, a great deal of improvement is still possible. Photodiodes, photosensitive FETs and photodarlingtontons all offer promise, but time has so far prevented further experimentation with them; furthermore, there are a number of alternative phototran-

sistors very much more capable than the BPX25 (which is itself a huge improvement over the FPT100, for example). Improvements in the detector sensitivity offer the greatest promise for increasing the range of this circuit.

Optics are another area where range improvements can readily be made. Simple lenses are all that's required. A lens in front of the detector can combine with its built-in lens to gather more light and to further narrow its acceptance angle; similarly, a lens properly positioned in front of the emitter can further narrow its beam width.

Emitter and detector characteristic wavelengths also require some attention. As Xciton points out in its data sheets on the emitters used here, for example, their 880 nm wavelength significantly improves coupling to silicon phototransistors, offering *twice* the coupling efficiency of

(continued page 38)

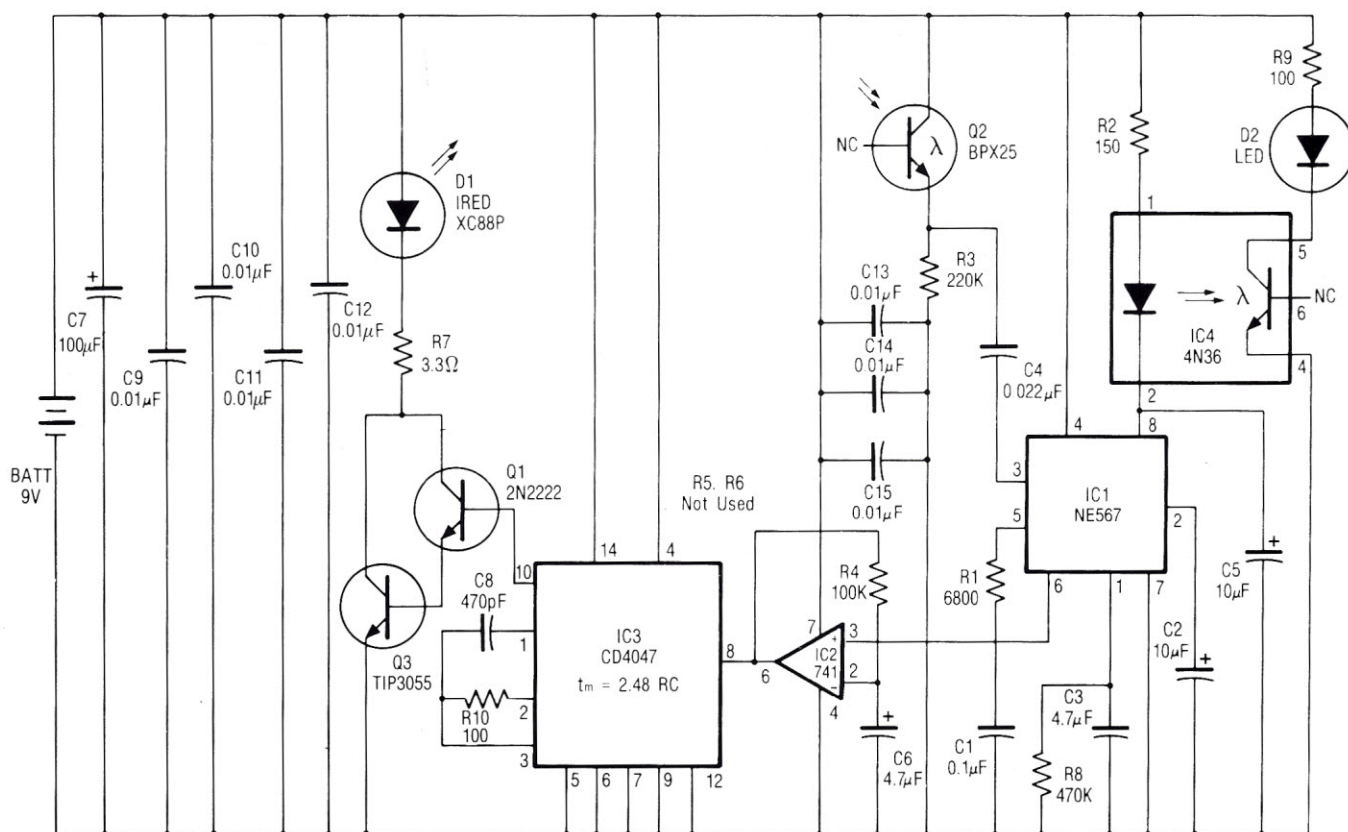


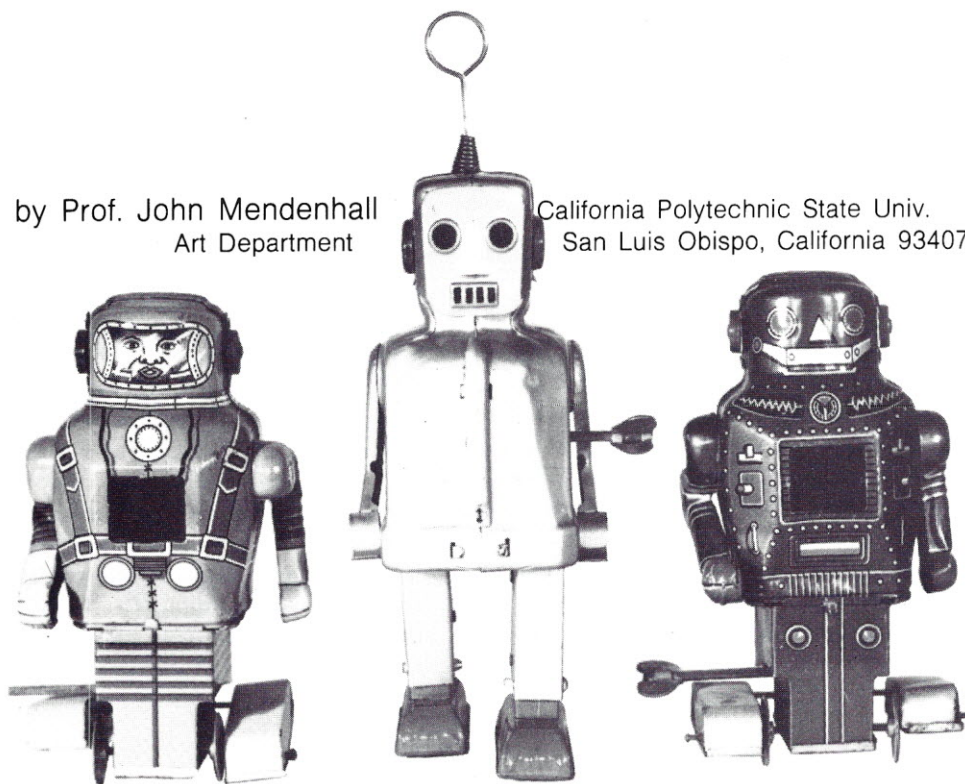
Figure 2. Improved circuit incorporates monostable narrow-pulse high-power driver, higher-power narrower-beam emitter, increased detector and PLL sensitivity and isolated output.

As shown and without external optics, a breadboard of this circuit was capable of responding to a human hand at 24 inches, white paper at 37 inches.

Component callouts have been normalized to Figure 1. C4, C7, R2, R3, R4 and D1 values have changed; C8-15, R8-10, IC3, IC4 and Q3 have been added; R5 and R6 have been deleted.

by Prof. John Mendenhall  
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San Luis Obispo, California 93407



# ROBOT TOY DESIGN

Human vanity being what it is, men will never tire of seeing machines made in their own image. Traditionally, robots have been conceived as machines created in the likeness of man to perform human tasks. Owing to the popularity of science fiction films and the toy robots which these movies inspired, the independently functioning robot (as friend or foe) has become a visible part of our popular culture.

From their conception, robots have tended to have human features such as arms, legs, faces and a vertical posture. This need to give mechanical devices anthropomorphic form predates science fiction films, as well as science fiction itself, by many centuries. In varying degrees all cultures have had a distrust of the machine and the rapid technological advances it makes possible. The personalization of machinery represents a fear of it: adding superfluous decoration or endowing it with human qualities is one way of coping with the unknown by making it more familiar.

The first clocks in cathedrals throughout Europe utilized life-size robot figures to strike the hours and quarter hours. While it would have been much easier to have a simple hammer strike the bells, the time-keeping machinery was humanized to provide a friendly, personal quality. Many of the ingenious automaton created in the 18th and 19th centuries were actually complex machines made to look like a child playing a musical instrument, creating a drawing, or engaging in some similar activity. The beautifully engineered system of gears, cams and spring mechanisms was not appreciated for its own sophistication, but had to be enclosed inside a human shell. While the automaton amazed the viewer by what it could do, it was still the figure, and not the machine, which was performing.

Looking into the future it was possible to conceive of machines capable of operating independently of man, yet nevertheless created in man's own image. One of the earliest autonomous robots appeared in Fritz Lang's film *Metropolis* in 1926. The robot was invented to replace an

actual woman, thus it was made to be indistinguishable from its human counterpart. Her initial metallic form (before synthetic skin was added) is a classic example of the angular, linear design popular during the 1920's and 1930's, and was the model for C3P0 in *Star Wars*.

Typically science fiction film robots reflect the level of technology at the time the film appears. The standard cinema robot of the 1950's was a metallic "tin can" shell with flexible duct piping for the arms and legs, as actual human actors had to fit inside to operate them. With the advent of space exploration, and as science fiction films and their followers became more sophisticated, robot design was updated to mirror technological advances. The drones in *Silent Running* and R2D2 in *Star Wars* are clearly machine-like with purely electronic speech. As we become accustomed to the continual presence of technology in our everyday existence, the prospect of robots with their own distinctly non-human appearance gradually becomes more acceptable.

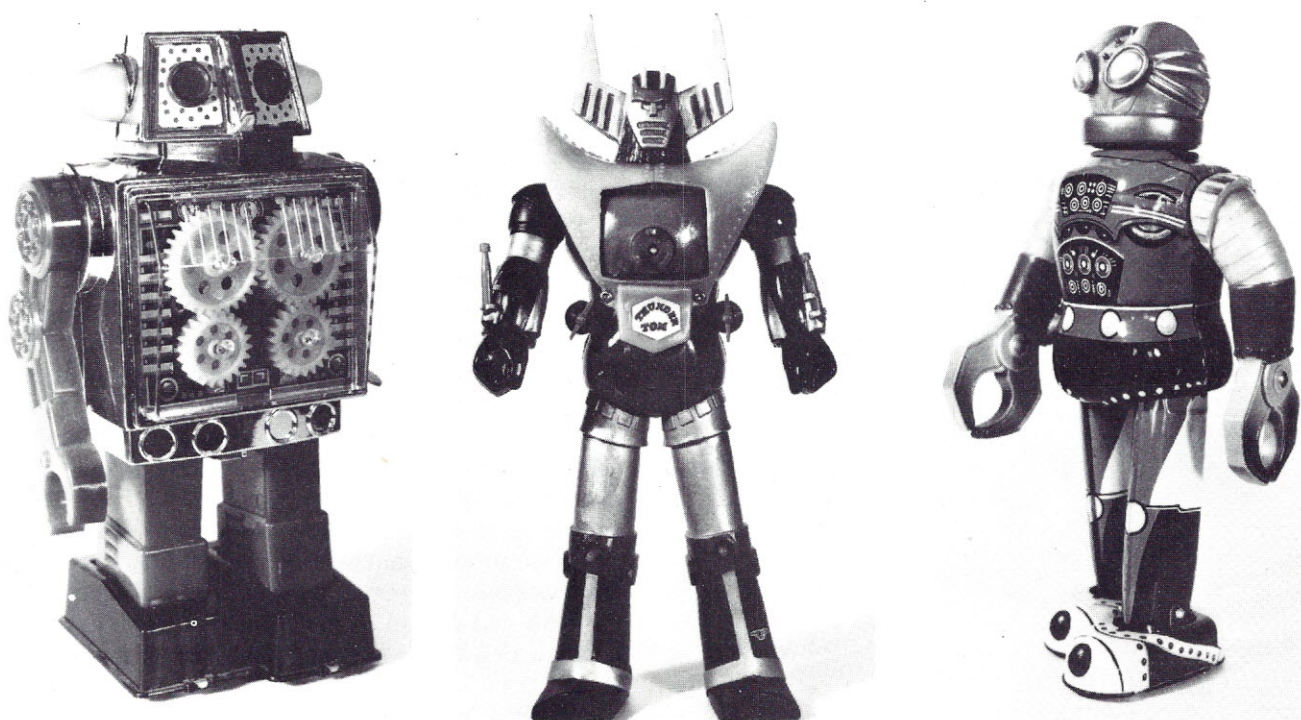
Just as the early automatons were toys for aristocrats, the first robots to be mass produced were toys for children. Toy robots started to appear on the market around 1945 and have increased in popularity as well as complexity throughout the years. As in science fiction films, most toy robots are recognizably humanoid in appearance, while some are an unusual combination of

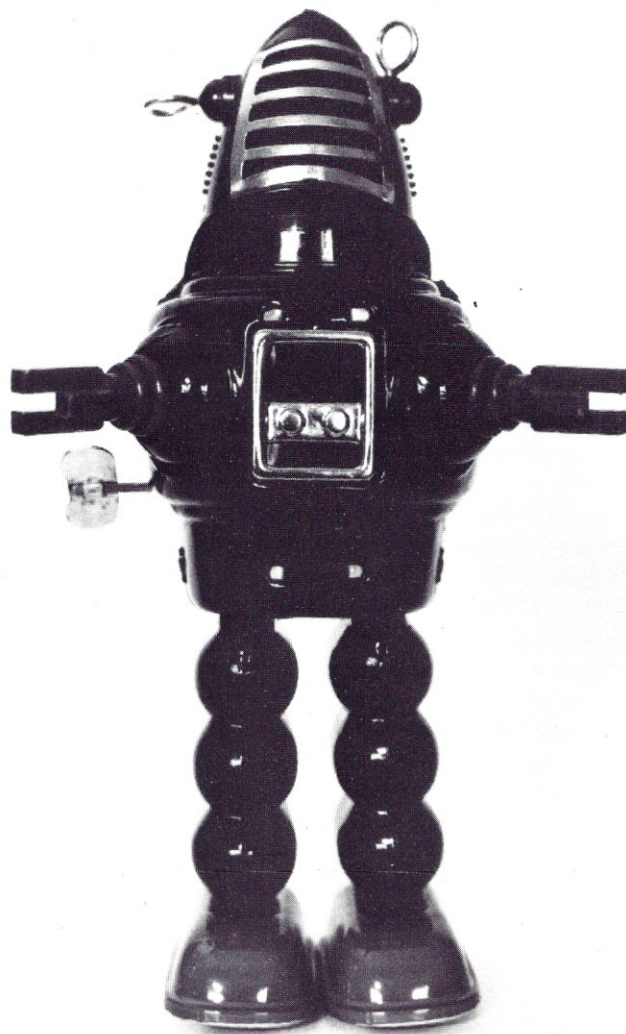
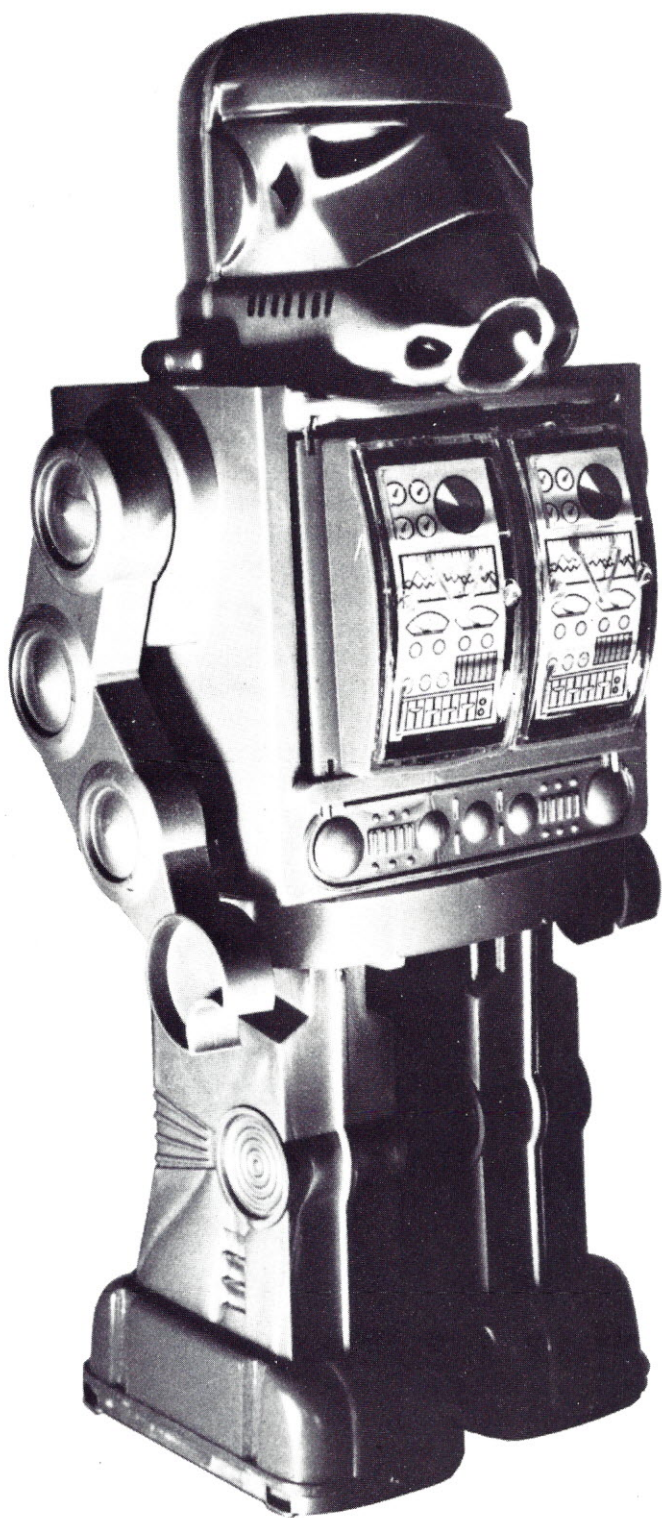
astronaut and machine.

The early toy robots were commonly made from colorfully lithographed metal which was stamped to create the body, arms and head. Most toy robots were manufactured in Japan and imported by American firms such as Rosko and Cragstan. Some were made in Germany, France and the United States, but by far the most ingenious are those designed by the Japanese.

Operating by either wind-up spring mechanism or battery power, the toys are capable of a variety of movements. Those operating by spring mechanisms usually walk, swing their arms and emit sparks from the chest. The introduction of battery-operated robots in the early 1950's allowed for more exciting actions, including blinking lights, space noises and continuous, though repetitive, motion. "Robert Robot," made by the Ideal Toy Corporation around 1954, is one of the earliest battery-operated robots: his arms move, his eyes and mouth light, and he is the first robot to talk. By turning a crank on a remote control box he says, "I am Robert Robot, the mechanical man. Guide me and steer me wherever you can."

What toy robots can be made to do seems limited only by the inventiveness of the designer. "Smoking Space-man" manufactured by Linemar in Japan has lighted pistons on his head, blinking eyes, and the amazing ability to smoke from his mouth. "Happy Harry the Hysterical

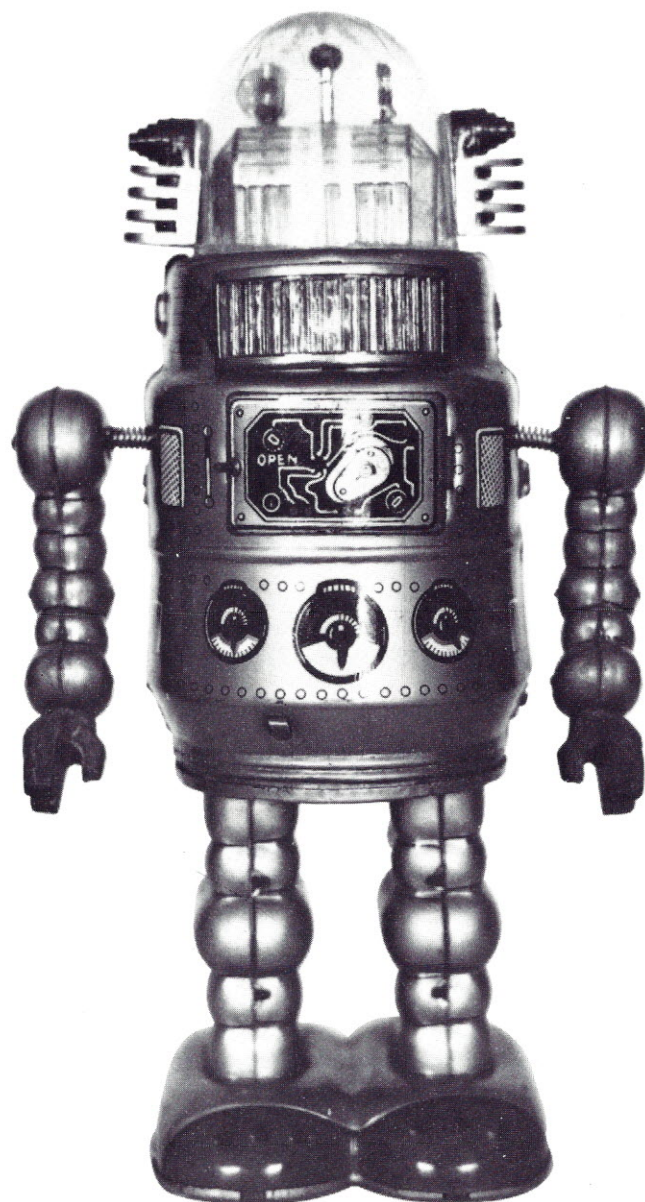
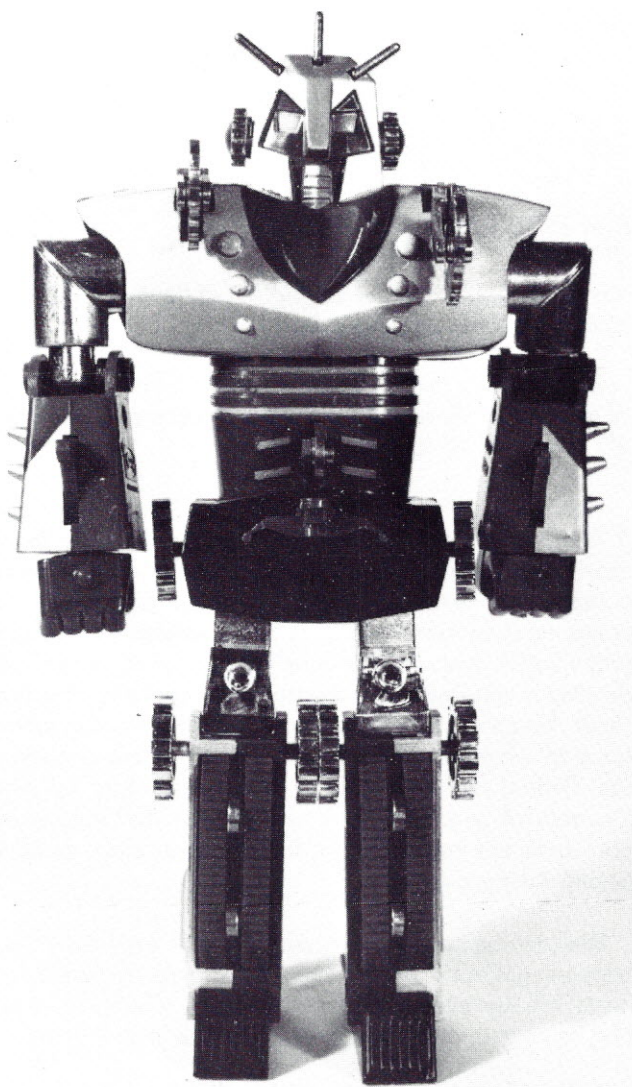




Robot" runs wildly on the floor, then stops suddenly. Doors open on his face revealing lighted teeth, his head bobs up and down, and true to his name he starts laughing hysterically. Some are more war-like, such as the "Space Fighter Robot" which walks forward, stopping occasionally to blast lighted guns from his chest.

Perhaps one of the most popular film robots was "Robby," who first made his appearance in 1956 in *Forbidden Planet*. His unique design epitomized the early stages of electronic technology, with mechanical abilities exceeding any seen in previous science fiction films. "Robby" influenced innumerable toy look-a-likes, as many manufacturers would copy a robot from a film but give it another name to avoid paying royalty fees. While there are many toy robots that obviously use "Robby" as a source, there was only one licensed version which was marketed in the USA and abroad. A toy collector could expect to pay upwards of \$400 for "Robby," if he is lucky enough to find one.

Following the trend of all toys, the colorful, highly



detailed metal robots of the past have been replaced by less interesting plastic versions. However, with the introduction of inexpensive micro-processors, a new breed of robot toy is developed which allows children to be more actively involved with the toy. "Rom," manufactured by Parker Brothers, is the first to utilize a silicon chip to create different sounds and sequences of blinking lights. Unfortunately, the dull green plastic "Rom" lacks the inventive actions of the earlier robots.

With the resurgence of interest in science fiction has come a parallel fascination with old space toys, particularly robots. Toy robot collecting is a worldwide phenomena which at times borders on the fanatic. Many collectors are more than willing to spend hundreds of dollars for toys which a few years ago would sell in nickel and dime stores for four or five dollars. There is a remarkable irresistibility in acquiring these early remnants of a naive, but charismatic, interpretation of our technological future. Yet while they are only toys, is it conceivable that they are forebearers of what their functioning counterparts will be? ®

## OPTO "WHISKERS"

(continued from page 33)

more common 940 nm infrared emitters.

Detectors that exhibit inconvenient tendencies toward swamping in the presence of high levels of ambient light can be desensitized by the simple expedient addition of an infrared filter in their optical path. (Obviously, there is no benefit in doing the same for the emitter!)

During experimentation, it was found that the intensity of the indicator LED varied to some degree (inversely) with distance; this might provide some facility for determining a reflectivity and/or range value for the detected object—bonus data for this very simple circuit.

Readers are encouraged to further develop this and similar circuit ideas and to communicate with the author or the editors via *Robotics Age*. Indeed, the capabilities of an improved inexpensive "whisker" of this sort extend beyond robotics to aids for the visually handicapped, alarm systems, automotive collision avoidance systems, automatic door controls and many other application areas. ■

## References

- [1] Richard Oliver, "Improve Photo Sensors with a Phase-Locked Loop IC," *Electronic Design News*, April 5, 1976, p. 112.
- [2] XC-88-PC "Super High Output Infrared Emitter, Xciton Corp., Shaker Park, 5 Hemlock St., Latham, NY 12110.
- [3] CQX-19 IR Emitter, AEG-Telefunken Semiconductors, Rte. 22, Orr Drive, Somerville, NJ 08876.
- [4] RCA Optical Communications Products, Solid State Division, Electro Optics and Devices, Lancaster, PA 17604.
- [5] Spectronics, a division of Honeywell, Inc., 830 E. Arapaho Rd., Richardson, TX 75081.
- [6] Texas Instruments, Inc., PO Box 5012, Dallas, TX 75222.
- [7] BPX25 Phototransistor, Ferranti Electric Inc., E. Bethpage Rd., Plainview, NY 11803.

Martin Weinstein is the author of *Android Design*, (Hayden Books, Rochelle Park, NJ) and is the author of numerous technical articles on home robot experimentation.

## ENGELBERGER INTERVIEW

(continued from page 23)

has an off switch it can't get too out of hand. But if they're building in fake off switches...

But you see, they're going to let on. In the early course of intellectual development they're not going to know that it's supposed to be kept secret.

There is talk now about ultraintelligent machinery (UIMs), where we use the CAD system to build better machinery, and we use the computer to design better computers. The machines get better each generation. The computers get more intelligent each generation, software optimization gets better and better. And when you develop a good software program it doesn't die. You don't think there's a chance they may get involved—I'm getting back to the great Greek/Roman myths—Zeus overthrew the Titans. Of course, Zeus was overthrown by man, Prometheus predicted it. You don't see that happening, you don't see our creation overthrowing man, or beneficially taking over?

Well, let me say this. I wouldn't want to say I don't see it happening. On the other hand, I don't think the risk is very great. I'm not even sure that it would be wrong, secondly. Maybe that is our destiny—evolution is still with us. ■

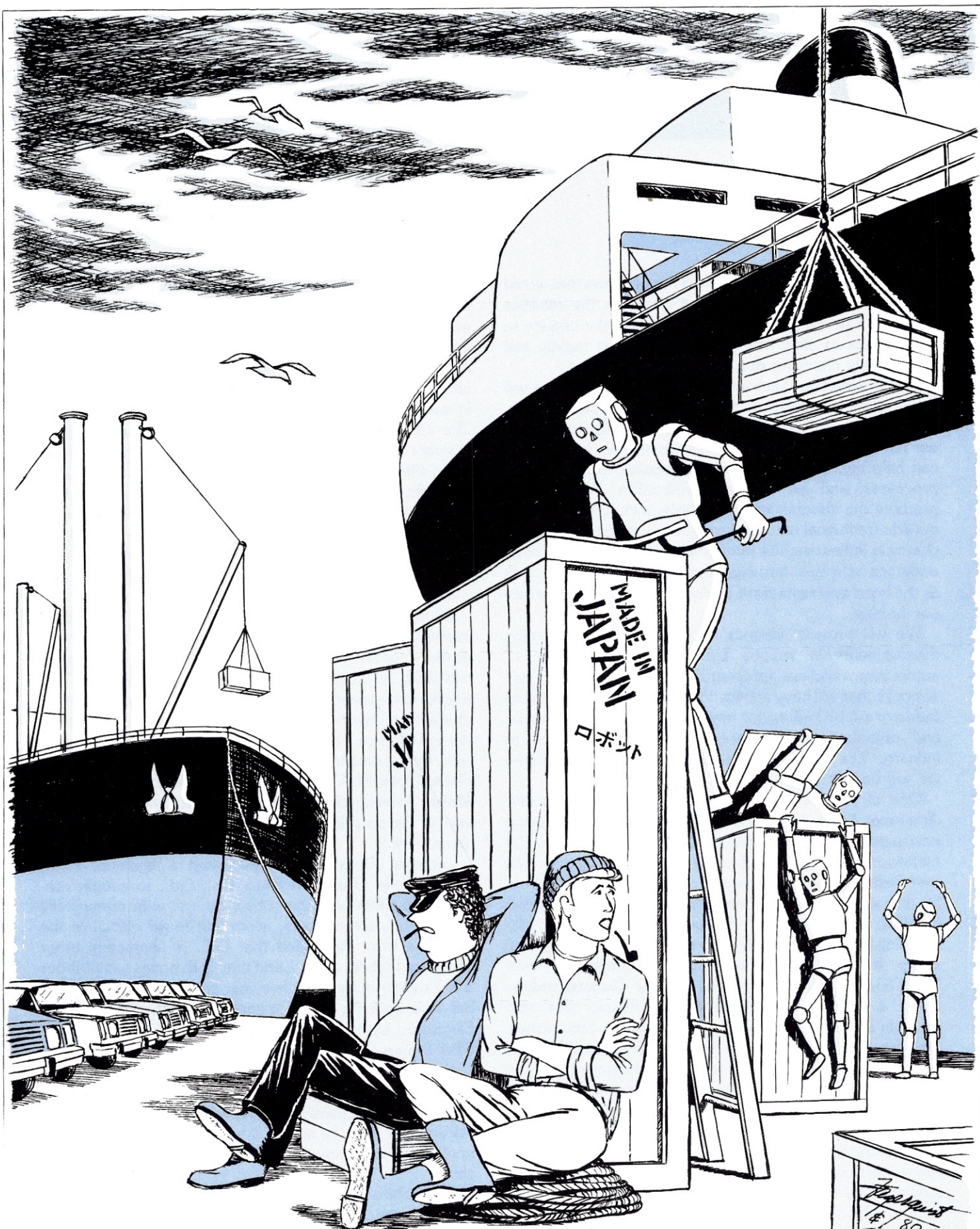
A review of Mr. Engelberger's new book, *Robotics in Practice, Management and Applications of Industrial Robots*, will appear in an upcoming issue of **Robotics Age**.

If you wish to purchase the actual tapes of this interview (the printed text was edited to reduce it to magazine length), please send a check to **Robotics Age**, Engelberger Interview, PO Box 725, La Canada, California 91011.

Send \$20.00 for two (2) high quality voice cassettes and index, add \$.75 for postage and handling, California residents please include 6% sales tax.

Our next interview is with Dr. Charles Rosen, formerly chief scientist with SRI International, and founder of Machine Intelligence Corporation.

If you have suggestions for candidates who should be interviewed or if you wish to make comments on the **Robotics Age** interview series please send them to the above address.



First it was transistor radios, then it was TV sets,  
now it's small cars. I wonder what comes next?

# Eye to Industry

by J. W. Saveriano

Many of our readers have asked for a column that would focus on new developments and trends in the robotics industry. Like most roboticists, I welcome the chance to discuss this exciting new technology that is rapidly and dramatically changing our world.

The information that forms the basis for the column will come from a variety of sources—various publications, discussions with experts in the field, and feedback from our readers. We will discuss methods and machines which can help improve productivity, rationalize manufacturing processes, and aid in reindustrialization. We hope to promote the dissemination of robotic technology to areas outside traditional manufacturing, such as the nuclear and chemical industries, the industrialization of space, mining, undersea activities, farming, commercial enterprises such as the hotel and restaurant businesses, and ultimately into our homes.

We will provide advance information on forthcoming developments in robotic technology in the fields of automation, artificial intelligence, and related computer sciences that will have application in manufacturing. *Eye to Industry* will be looking for newsworthy data on the people and organizations that are making things happen in industry. The following are examples of the kinds of items we will be offering.

One of my favorite sources of industry news is the *American Metal Market*, *Metalworking News*, a weekly newspaper that actively reports on news pertinent to the metalworking industries. In recent articles they reported that Detroit is planning on stepping up purchases of robots for use in spot welding, assembly, sorting, and material handling jobs. **General Motors Corp.** is reportedly planning to buy up to 1,800 or so robots by 1984. **Chrysler Corp.** is using 24 Unimate robots in conjunction with ROBOGATE framing systems built by **Comau Industries**, a division of Fiat Motors,... Chrysler has also recently signed up for another 400 robots to add to their growing robotic workforce. This is certainly good news for the major robot builders—it will also encourage others to enter the growing marketplace. On the other hand, with the Detroit giants gearing up for such extensive use of robots a couple of negative side-effects may occur, the first being increased lead time on deliveries and the second being increased catering to the needs of the automotive industries by the robot builders, who may become reluctant to help solve some of the tougher batch manufacturing problems that exist outside of Detroit.

*Newsnotes...* **Planet Corp.** has added a new member to its family of ARMAX robots. This new addition is a 5-axis wirebrush-welding robot which uses force feedback to adapt for brush wear and part variation. One was recently shipped for use in deburring operations in the automotive industry... **Automatix**, Inc. of Burlington, Mass., formed in early 1980, is pleased with its first year performance. The company has shipped about ten stand-alone vision systems and six Model AID 800 welding robot systems using **Hitachi** robots in an OEM agreement... **Yaskawa Electric Machinery**, Ltd. of Japan recently signed an agreement with **Hobart Bros. Co.** of Troy, Ohio. Hobart will provide marketing, engineering, and service support for Yaskawa's computer-controlled, electric-powered welding robot, 300 of which are running worldwide in arc welding applications.

**Control Automation**, Inc. of Princeton, N.J. will be introducing a new robot in the near future. Final design features are not yet released. The company was formed in mid-1980 by Gordon I. Robertson, president, and Tony Rodde, vice-president. Previously, both worked together at Western Electric, and hold PhD's in Electrical Engineering and Physics, respectively. The new company is backed with the assistance of Fredric Adler, who helped start **Data General Corp.**... **American Can** will distribute **Mobot Industrial Robots**, which recently went public, as part of its propriety automation systems and its stand-alone devices.

**General Electric Co.** has asked a Japanese robot manufacturer, **Dainichi Kiko Co., Ltd.**, to submit estimates on parts handling robots for use with numerically controlled machine tools, according to an official of the Japanese firm. He added that G.E. is contacting other Japanese makers as well, and that G.E. hopes to sell about 8,000 robots in the next five year period. General Electric has also signed a licensing agreement with **DEA** (Digital Electronic Automation) of Turin, Italy to build and sell the DEA Pragma 3000 industrial robot. The Pragma 3000 is a sophisticated robot that can be applied in parts handling, assembly, and inspection of small parts in the 1.5 Kg range. G.E. has the exclusive selling rights in the US, Canada and Mexico, but they are not likely to pursue sales of this robot until they gain some in-house experience with the machine.

Prab robots may now be purchased without controllers. **Walt Weisel**, vice-president of **Prab Conveyors, Inc.**, says that customers will be able to connect the robots

directly to NC machine tools or can use programmable controllers to provide the robots with instructions. Prab currently has some 600 machines running in the field, with most applications requiring fewer than 30 steps per program. This new marketing philosophy allows the customer more latitude for reducing system cost by use of existing or less expensive controllers... General purpose programmable automation will be required if **ICAM** (Integrated Computer-Aided Manufacturing) is to become a reality. This seemed to be the consensus of the conferees who attended a workshop at the National Bureau of Standards sponsored by the Air Force ICAM project. Five areas that might benefit from standardization were identified as: simple sensor interfaces between robot and ancillary devices, interfaces between wrist and gripper, interfaces allowing independent trajectories for robots, interfaces for complex vision, touch, and for data bases and off line programming.

**Ransburg Corp.** signed a preliminary agreement with a unit of Regie Nationale des Usines **Renault** of France to manufacture industrial robots in the US. The joint venture will be owned 51% by Ransburg and 49% by Renault. Production is expected to begin Oct. 1. Ransburg makes electrostatic-coating systems. Because of the recent acquisition by Renault of interest in **American Motors**, we expect to see Renault robots appearing in AMC plants... **Kulicke & Soffa**, makers of semiconductor assembly equipment, are forming a subsidiary to manufacture industrial robots. The company expects the new product to be a "major" part of its operations. Its initial product will be a line of table sized "pick and place" robots, which will handle loads of up to five pounds. The robots would be used for electronics assembly, testing, packaging, and in general manufacturing where productivity gains and unit cost reductions are vital.

Several hundred AI researchers and government/military personnel attended the **Military and Space Applications of Robotics** conference, held early last November in Washington, DC. The conference, sponsored by the Naval Research Lab, provided an opportunity for potential government users of robots to get acquainted at first hand with some of the more recent developments from the academic and industrial community. With the exception of one speaker who speculated on possible battlefield applications of robots, the emphasis was on automating important military support functions, including fabrication and maintenance tasks. The conference gave academic centers the opportunity to present their work to potential new funding agencies now considering the support of specialized robotics development/application.

*Running Rumors...* **IBM** is expanding its manufacturing facility in Boca Raton, FL. Is this to be the birthplace of IBM's robot? We heard that some minor mechanical problems have caused delays for **Texas Instruments** in introducing their small electric manipulator. And how long will it be before **Cincinnati Milacron** enters the "small arms race"?

*Eye to Industry* will also report on courses, seminars, conferences and meetings related to Robotics. Two such important events were sponsored by the **SME** (Society of Manufacturing Engineers) in conjunction with **RI** (Robotics International) and the **CASA** (Computer and Automated Systems Association). Both RI and CASA are associations of SME. In late October of 1980, the enormously successful **ROBOTS V** Conference and exposition was held in Dearborn, Mich. (see page 24 for a report on this conference). In November, the SME/RI/CASA held the Autofact West Conference and Exposition in Anaheim, Calif., emphasizing the "automated, integrated factory of the future." Most of the equipment shown at this exposition was related to Computer-Aided Design (CAD) using interactive graphics. However, the papers given at the conferences covered the broad spectrum of CAD-CAM and Robotics. Also of note was the well attended first meeting of the Southern California Chapter of Robotics International of SME. RI/SME is an individual membership organization for professional engineers and managers interested in robotics, contact SME/RI, One SME Drive, Box 930, Dearborn, Michigan 48128, for details.

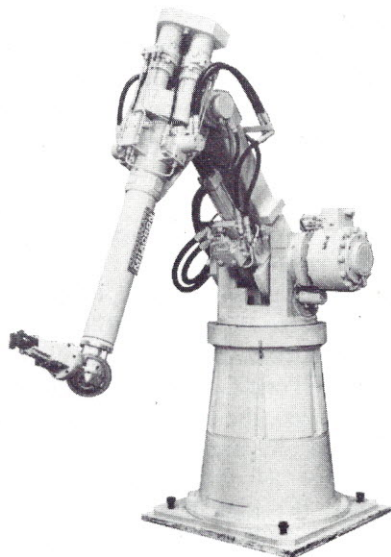
If you have robotics-related information that you believe is noteworthy, or have suggestions for topics for this column, please write to us at:

*Eye to Industry*  
**Robotics Age**  
 P. O. Box 725  
 La Canada, California 91011  
 or call (213)352-7937

*Be seeing you!*

# NEW PRODUCTS

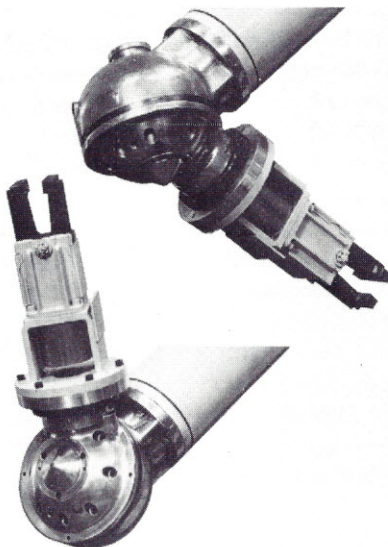
## Milacron Introduces T<sup>3</sup>R<sup>3</sup> Robot



The newest industrial robot from Cincinnati Milacron, the T<sup>3</sup>R<sup>3</sup>, features a new wrist configuration designed to provide increased flexibility in performing intricate process applications. The new design, called the Three Roll Wrist, is shaped like a sphere (about 8 inches in diameter) and consists of three roll axes. The two axes closest to the robot forearm work together to give the T<sup>3</sup>R<sup>3</sup> 230° of pitch (up and down) and 230° of yaw (side to side) motion. The other roll axis (that farthest from the forearm) allows continuous rotation of the hand or tool.

Most three-axis wrists include at least one bend axis, which adds to the size of the wrist. However, a great number of process applications demand a wrist that is more compact and flexible. The Three Roll Wrist provides both the necessary compactness and flexibility and at the same time has a weight-handling capacity more than sufficient for most process applications—50 pounds at 10 inches from the tool mounting plate.

Consistent with its compactness,



the Three Roll Wrist contains few parts. Three concentric shafts that drive the axes pass through the tubular forearm and are powered by hydraulic motors mounted at the robot's elbow. The light weight and compactness of the wrist result in low inertia for each wrist axis, and the rigid, spherically shaped housing and reliable remote drive system provide the stiffness required for good servo control. Each axis has its own feedback device consisting of a resolver and tachometer to provide a standard positioning accuracy of  $\pm .020$ ".

The T<sup>3</sup>R<sup>3</sup> Robot has three axes in addition to the three at the wrist, giving it a total of six degrees of freedom. The base and upper arm of the T<sup>3</sup>R<sup>3</sup> are identical to those on the proven T<sup>3</sup> Robot. The basic control and teaching method are the same as well. As with the T<sup>3</sup> Robot, teaching the T<sup>3</sup>R<sup>3</sup> involves guiding the robot through its task using a lightweight, hand-held teach pendant.

Contact: Cincinnati Milacron, Cincinnati, OH 45209. (513)841-8756.

CIRCLE 1

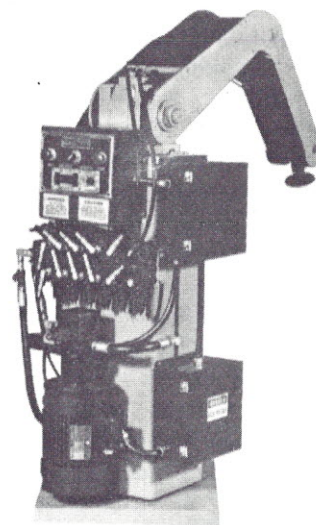
## New "Series Three" Robot from Thermwood

The Series Three general purpose robot is a five-axis, jointed arm, servo-controlled, point-to-point industrial robot designed for material handling and welding applications. The 50 lb. payload robot includes a self-contained hydraulic system and is capable of .060" position repeatability and programmable velocities up to 45°/sec.

The basic 200 point memory capacity may be expanded, and up to 99 programs can be stored at one time and linked together through the robot's operating system. The robot is programmed with a hand-held keypad, which also permits program editing. An optional magnetic tape unit for program storage is also available. The system features a complete set of built-in diagnostic functions for fault isolation, and the company offers overnight delivery of replacement modules.

The base price for the Series Three is \$29,000. Thermwood Corporation, P.O. Box 436, Dale, IN 47523. (812)937-4478.

CIRCLE 2



### **Programmable Robotic Arc Welding System Features Easy Teach Software**



The Robovision I System from Automatix, Inc., includes the AID 800 all-electric, five-axis robot and controller, the Lincoln Electric Company heavy duty power supply, wire feeder, and welding software for precise control of torch position and welding parameters. Repeatability of the Robot is  $\pm 0.008$  in. ( $\pm 0.02$ mm). Simple teaching methods allow the robot to be employed in welding small batches of parts, since the teach time is a small part of the weld process. In addition, multiple part types can be intermixed and welded since the Robovision I System stores many part welding programs. The system provides for Cartesian or joint angle robot control while teaching. Also, pre-stored welding parameters can be recalled by the operator to facilitate the teaching process. High productivity is achieved by simplified teaching coupled with a parts feed system and positioner which allows one fixture to be loaded while the robot is welding on another.

The Robovision I System is

lightweight and utilizes a space saving 5-axis jointed arm design which allows floor or overhead mounting and facilitates complex part welding. Initial product deliveries are scheduled starting in November 1980.

For further information contact Automatix, Inc., 217 Middlesex Turnpike, Burlington, MA 01803. (617)273-4340. **CIRCLE 3**

### **Hobart System Features Yaskawa Robot**

The Robot Arc Welding Center at Hobart Brothers Company, Troy, Ohio has added the Japanese-built Yaskawa L10 industrial robot to their Procedure Laboratory. The L 10 is an all-electric robot designed specifically for arc welding.

The robotic welding package includes: 1) the Motoman robot manipulator and control; 2) a Hobart arc welding package consisting of matched power source, wire feeder with gun/cable assembly and interfacing controls; 3) fixturing or positioners for weldments and 4) robot arc welding system engineering.

A key part of the package is the interfacing control designed by Hobart Brothers to marry the welding system to the Motoman's control. The arc welding package was designed so that the wire feed speed and welding voltage can be controlled by the same computer that controls the robot's motions. Welding conditions can be programmed to change as readily as the direction or speed of the robot manipulator can be changed.

As a distributor for Yaskawa, Hobart Brothers has installed a complete Motoman L10 robot welding system in their Troy, Ohio,

Technical Center. Visitors are welcome to observe free demonstrations of the robot welding parts for Hobart products. The Center will also review parts or drawings to determine the feasibility of your weldment or part for robotic welding. If your weldment is suitable, technicians at the Center will program the robots to demonstrate how they could weld your part. This service, which includes a methods analysis and report done for a fee, will enable you to decide if an arc welding robot is suitable for your plant.

For more information, contact the Advanced Welding Technology Group Hobart Brothers Co., 600 W. Main St., Troy, OH 45373. **CIRCLE 4**

### **Spatial Data Systems Announces New, Rack-Mounted Picture Digitizer & Display System**



Designed specifically for those image processing applications where the operator's position must be remote from the host computer, or for installation in an industrial environment, Spatial Data's new Model 109RM (rack mounted) is offered. Rack-mounted system contains all the electronics of Spatial Data's Model 109PT in a single package.

Electronics are expandable to

include up to 24 bits of Model 808 refresh memory and can also accommodate 21 bits of refresh memory with real time digitizer and real time processor.

Separate keyboard and joystick (Model 109KB) and B/W display (Model 108D) combine with the Model 109RM to provide all features and functions of the Model 109PT for remote operation.

For further information, contact: Spatial Data Systems, 508 South Fairview, Goleta, CA 93017. (805) 967-2383.

CIRCLE 5

### Chess Playing Robot



The newest model of the popular BORIS series of home chess computers comes equipped with its own robot arm attached to the chessboard, allowing the computer to carry out its own moves and captures. The BORIS HANDroid™ features the new BORIS 2.5 chess program, winner of the 1979 European Microcomputer Chess Championship.

The machine is capable of play at seven strength levels, with higher levels requiring increasingly more time to compute moves. Playing at its fifth level (2-4 minutes per move), the program earned an unofficial rating of 1641 under USCF rules.

Sensors in the chessboard auto-

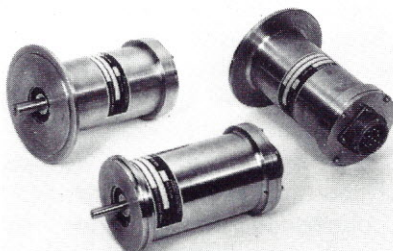
matically detect your moves, eliminating the need for keyboard entry during play. Other features of the system include programmed message displays, audio alerts, a tournament timer, position storage memory, and keyboard entry for game practice and chess problem solving.

The BORIS HANDroid costs \$1,495. The modular chess computer alone costs \$295, including the BORIS 2.5 chess module, with an optional checkers module for \$59.95. Available from PMK Associates, P.O. Box 598, E. Brunswick, NJ 08816. 201/246-7680.

CIRCLE 6

### Brushless Resolvers for Industrial Applications

Industrial sensors designed to be coupled directly to factory equipment, such as a machine tool lead screw or other rotary mechanism, are now available from the Singer Company's Kearfott Division. Used as the resolver feedback units in closed-loop control applications, these single and multispeed resolvers are built with oversize shafts, ruggedized bearings, sealed rear connector and double-sealed front bearing. The multispeed units do not require the use of gears to obtain scale variations, resulting in the elimination of periodic gear backlash adjustments and other related problems, improving the MBTF from



276,000 hrs. to 880,000 hrs.

The Kearfott CR9 1095 005 brushless resolver is approved as intrinsically safe for Class I, Division I, Group C and D hazardous locations as defined by Article 500 of the National Electric Code. Brushless resolvers use a rotary transformer to couple power into the rotor in place of standard brushes and slip rings.

Also available from Singer-Kearfott are several new brochures detailing the Kearfott rotary sensor product lines: "Brushless Resolvers for Industrial Applications," "Single and Multispeed Brushless Synchros and Resolvers," and "Motor Tach-Generators." For further information, contact D. Katz, Kearfott Division, The Singer Company, 1150 McBride Ave., Little Falls, NJ 07424. (201)256-4000.

CIRCLE 7

### High-Resolution Shaft Encoder



The Litton Model 81 is a 1.5" diameter by 1.10" high optical incremental encoder. Precision ball

bearings and TTL electronic compatible outputs are utilized in the unit, along with the highly reliable Gallium Arsenide light sources which carries Litton's five-year guarantee against field failure. Standard units can provide two channels of up to 1024 cycles per revolution. A zero index 3rd channel is available as well as +5, +12, +15, or +24 volt operation.

A technical bulletin is available. Send inquiries to: Marlene Votion, Litton Encoder Division, 20745 Nordhoff Street, Chatsworth, CA 91311. (213)341-6161, ext. 192.

CIRCLE 8

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### **16-Channel Miniature Modular Data Acquisition System**

A 12-page technical brochure by Datel-Intersil details all the electrical and mechanical specifications of their 16-channel single ended (8-ch. differential), 12 bit resolution, 72 pin miniature data acquisition systems, Models MDAS-16 and MDAS-8D. These modules are ideally suited for use in low level signal applications involving bridge amplifiers, transducers, strain gauge and thermocouple interface. Other features in this brochure include block diagrams, technical notes and applications. Available free of charge from: Datel-Intersil, 11 Cabot Blvd., Mansfield, MA 02048. (617)339-9341.

CIRCLE 9

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### **A Pin-Compatible ROM Simulator**

A ROM simulator is a block of read/write memory physically located in a "host" computer. The simulator takes the place of ROM, PROM, or EPROM normally located in the target machine. The ROM

simulator plugs into the socket in the target computer by a 24-pin DIP connector and ribbon cable.

ROM simulators are extremely useful for developing software that will eventually be placed in ROM in the target computer. During the development process, which normally requires numerous cycles of testing and changing, the need for downloading to the target computer is eliminated. Similarly, the need for RAM in the target machine is reduced. Another advantage is that programs loaded into the simulator appear in the exact memory location they will ultimately reside in the target machine.

The Lamar Instruments ROM Simulator is designed to reside in an APPLE II based development system. The 2.75"x7" wire-wrapped card contains 2K bytes of static RAM located from C800 to CFFF in the APPLE II memory space. It also contains the logic necessary to automatically switch control of the address and data bus from the APPLE II to the target machine's ROM socket. The board is \$395.00, available immediately from Lamar Instruments, 2107 Artesia Blvd., Redondo Beach, CA 90278. (213)374-1673.

CIRCLE 10

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### **Cromemco Announces New I/O Processor**

Cromemco's new I/O Processor (Model IOP) provides Multiprocessor capability for Cromemco's S-100 bus microcomputer systems. The IOP is a single-card computer with a Z-80A microprocessor, 16K bytes of RAM and up to 32K bytes of PROM capacity.

The IOP can be used either alone or with other IOP cards as a satellite processor on the S-100 bus

processor and a set of peripherals. These peripherals are controlled over a new bus, called the C bus, which operates independently of the S-100 bus. Devices such as Cromemco's QUADART serial I/O card can be interfaced through the C-bus connector on the top edge of the IOP card.

To the host processor, the IOP appears as two output ports and two input ports. The base address of these ports is switch selectable. In addition, the IOP can interrupt the host processor and supply a pre-programmed interrupt vector. A daisy chain connector is used for prioritizing interrupts.

The Model IOP card is available assembled and tested for \$695. For additional information, contact Cromemco, Inc., 280 Bernardo Ave., Mountain View, CA 94043. (415)964-7400.

CIRCLE 11

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### **Books, Courses Feature Cuk Converter**

The Cuk power converter represents a breakthrough in switched-mode power processing circuit design. The patented circuit, developed at Caltech by Profs. S. Cuk and R. Middlebrook, employs an entirely new switching topology to isolate switching pulses between input and output inductors, resulting in high efficiency, low EMI, and reduced parts count. Converter designs employing coupled input and output inductors and isolation transformers are capable of entirely eliminating current ripple at the input or output terminals or at both simultaneously, resulting in a physical realization of a near ideal dc-to-dc "transformer." In a patented push-pull configuration, the circuit may be used for highly efficient

servo/power amplifiers.

A two-volume collection of technical papers on the development, extension, and application of the Cuk converter is now available from TESLaco, Inc., which is also the firm licensed to develop products and commercial applications based on the Cuk converter. The volumes contain papers presented at major power electronics conferences (POWERCON, IEEE-PESC, etc.) as well as original tutorial material explaining the design and functioning of the converter and its numerous applications. TESLaco is also offering a 3-day intensive course on power conversion circuit design featuring the Cuk converter as well as earlier designs.

The two-volume set, "Advances in Switched-Mode Power Conversion,"

(over 450 pp.) is available for \$40 (shipping included) from TESLaco Educational Division, P.O. Box 3817, Thousand Oaks, CA 91359. (805)499-4150. **CIRCLE 12**

### Brochure on AI Research

A new brochure provides a description of the Artificial Intelligence research carried out by Stanford's Heuristic Programming Project and of the major AI systems developed by the Project since it was founded in 1965. These systems include DENDRAL, which analyzes mass spectrometer results, MYCIN, which analyzes infections and prescribes treatment, and MOLGEN, which aids the design of genetic

engineering experiments. These programs and others developed at HPP helped establish the field of *knowledge engineering*.

An article on the history of the Project and a glossary of relevant terms are followed by short descriptions of 16 AI programs grouped according to special applications in science, medicine, engineering, and education. Listings of the Project's staff (1965-1980), Ph.D. dissertations, funding sources, and recommended related readings are appended.

The cost of the brochure is \$2.75 per copy (payment required in advance), from: Stanford University, Dept. of Computer Science, Attn: HPP Brochure Sales, Stanford, CA 94305. **CIRCLE 13**

## The Brains of Men and Machines

Ernest W. Kent



## THE BRAINS OF MEN AND MACHINES

As researchers begin to unravel the mysteries of the brain's chemical, electrical, and synaptic circuitry, their findings are becoming immediately applicable to advances in robotic behavior and computer design. *The Brains of Men and Machines* "dissects" the brain to provide new insights into robotics, computer design and artificial intelligence. It is one of the rare books that transcends disciplinary boundaries. In it the ever increasing relationship between man and machine is freshly examined—a relationship, Professor Kent concludes, that is today being reexamined in the light of man's own neurological self-image.

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# MEDIA SENSORS

*Time* (cover story), Dec. 8, 1980, **The Robot Revolution.** Where there were once 200 welders on an assembly line, today, at Chrysler's Jefferson Plant, there are no welders in sight—there are only 50 robots "craning forward spitting sparks." Output is up 20% with robots, and they work two shifts.

In Italy, a new \$110,000 robot called Pragma A-3000 is assembling compressor valves from 12 separate parts. It has two arms that can work independently. If it picks up a defective gasket, it discards it and picks up another. It produces 320 units an hour, without mistakes. That's roughly equivalent to 10 workers. Furthermore, it can easily be re-programmed, theoretically, to assemble just about anything.

The robot is finally emerging from science fiction and beginning to transform the world. This robot revolution promises to give smaller firms the benefits of mass production and ultimately it may transform the way society is organized.

Some experts see dangers. If robots can do men's work cheaper and better than men, what will men do?

The robot revolution originates in American industry's stagnation in productivity. Economic planners see in the robot a solution to this problem.

Two key developments contribute to the trend: the microprocessor chip, which made a cheap robot controller possible, and wage inflation, which increased the cost of human workers. Today robots cost \$4.80 an hour, versus \$15 to \$20 for a human. That is the formula for a gold rush.

Overall, the fledgling U.S. robot industry is projecting sales of \$90 million this year. Wall Street analysts predict a growth of 35% a year, which

gives a sales potential of \$2 billion by 1990. Some talk of a \$4 billion a year volume.

Spurring U.S. manufacturers are foreign competitors. The Japanese operate most of the robots in the world (10,000, versus 3,000 in the U.S. and about the same in Europe). They are also outproducing the U.S. in robots by at least 5 to 1. "Unless we start doing something to increase U.S. productivity, the United States will be out of business as a country," says Julius Mirabal of General Electric, after returning from a tour of Japanese factories where he found robots everywhere.

The fact that the robot's instructions can be changed is critically important. 60% of U.S. manufacturing is done in batches too small for special-purpose assembly lines. Robots could reduce cost in small lot manufacturing by 80% to 90%.

The effort now is to make robots smarter so they can see and hear. With machine vision, robots can scan parts and make judgements on which one to pick up.

Researchers at MIT have a robot with "the mentality of a child 1½ years old." They claim that the advanced model under development will probably have the mentality of a five year old.

A sense of the robot as a helper rather than a menace is widespread among factory hands. Often human partners will affectionately give the robot a name. The willingness of robots to do the dirty jobs people don't want has muted alarm over loss of these jobs. But as robots take over the more pleasant jobs the unions' cooperativeness may change.

Leaders in the robot industry claim that resistance to their inventions comes from manage-

ment, not union labor. To persuade management, one uses the hard language of survival. "If we don't go to robots we'll just continue to lose to Japan and West Germany," says one robot expert at Carnegie-Mellon University.

According to Edward Fredkin of MIT, "We are creating what is going to be an immense new industry, perhaps as big as the auto industry."

A forecast by the Society of Manufacturing Engineers and the University of Michigan concluded the following:

- By 1982, 5% of all assembly systems will use robot technology.
- By 1985, 20% of the labor in the final assembly of autos will be replaced by automation. In the same year robots will be able to select parts from a bin.
- By 1987, 15% of all assembly systems will use robots.
- By 1988, 50% of small-component assembly will be automated.

Uniquely in History," says British Agriculture Minister Peter Walker, "we have the circumstances in which we can create Athens without the slaves."

**Media Sensors** are brief summaries of robotics-related items that have appeared in the mass media. An attempt is made to paraphrase the content of the original item without altering the tone. The views expressed in these items are not necessarily those of *Robotics Age*. If you have an item you would like to contribute, send it along with a complete identification of its source, to:

*Media Sensors*  
*Robotics Age*  
P. O. Box 725  
La Canada, CA 91011

# ORGANIZATIONS



## Unimation's Stan Polcyn to Head Robot Institute in 1981-82

The 1981-82 President of the Robot Institute of America (RIA) is Stanley J. Polcyn, Vice President/General Manager of Unimation Inc., Danbury, CT.

Polcyn was installed at the ROBOTS V Conference and Exposition held at the Hyatt Regency Dearborn October 28-30. The three-day event drew 6,508 attendees from 38 states and 14 countries.

Polcyn succeeds John Fulmer of the Industrial Robots Division, Cincinnati Milacron Inc., as RIA President and will serve for two years. In assuming the RIA presidency, Polcyn said that robotics—as demonstrated during ROBOTS V—is a leading-edge technology for the improvement of industrial productivity in the USA and that robots will play a pivotal role in America's reindustrialization to regain leadership among industrial nations.

"Top management must be made aware and recognize that these opportunities exist today—robotics

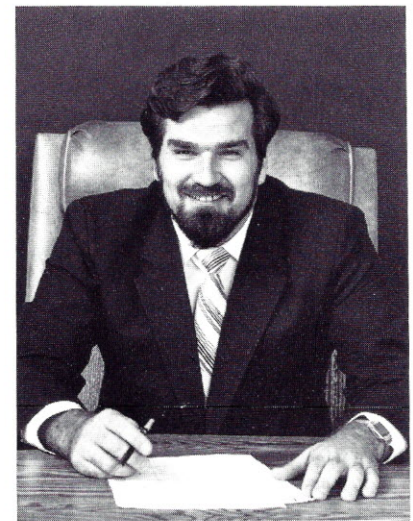
technology is in place and working right now in hundreds of American factories and foundries," he said, adding that RIA estimates put America's robot population at more than 4,000 units.

Polcyn has been a member of the

Robot Institute's Board of Directors since 1976. Before joining Unimation in 1972 he had been marketing manager of the Crane & Hoist Division, Bresser Industries, Muskegon, MI. Polcyn and his family live in Newtown, CT.



Dr. Robert D. Middlebrook



Dr. Slobodan M. Cuk

## Cuk Converter Wins National Award

A power converter invented by two Caltech faculty members has been awarded a national prize as one of the most significant inventions of 1979. The device, which converts form one direct current voltage to another, was developed by Assistant Professor of Electrical Engineering Slobodan M. Cuk and Professor of Electrical Engineering Robert D. Middlebrook.

The "Cuk Switching DC-to-DC Converter," as it is called, was selected as one of the 100 most significant inventions of 1979 by *Industrial Research/Development Magazine*.

Such converters are vital components in a wide range of devices, including computers,

spacecraft, solar arrays, electric motors, and audio amplifiers.

The Cuk converter is more efficient than other such devices, and is smaller, lighter, and has high reliability. It also produces an output voltage with very low ripple and little electromagnetic interference.

Development of the converter was sponsored by NASA's Lewis Research Center of Cleveland. Drs. Cuk and Middlebrook and a representative of NASA-Lewis attended a ceremonial banquet at the Chicago Museum of Science and Industry to receive the award along with the other winners.

Drs. Middlebrook and Cuk direct the Power Electronics Group at Caltech, which includes both

research and courses on the design and analysis of devices for power conversion. Patent rights for the new power converter are held by Caltech.

Because of its many potential applications in robotics for power conditioning and servo amplification, the Cuk converter was featured in a two-part article in *Robotics Age*, "Advances in Switched-Mode Power Conversion." Reprints are available.

Commercial applications of the Cuk converter are being directed by Teslaco, Inc. of Pasadena, Ca. In addition to product development, the firm also conducts seminars on power converter design and offers a two-volume collection of technical papers on the Cuk converter. (See *New Products*).

#### *Announcements:*

#### **SME Names Robert L. Vaughn President-Elect for 1981-1982**

Robert L. Vaughn, Chief Manufacturing Engineer of the Space Systems Division, Lockheed Missiles and Space Company, Sunnyvale, CA, is the 1981-82 President-Elect of the Society of Manufacturing Engineers.

Vaughn was named President-Elect at SME's recent semi-annual meeting in Chicago and will be installed as President of the 54,000-member engineering society at SME's 1981 International Tool & Manufacturing Engineering Conference and Exposition in Detroit next April 27-30. He will succeed Robert A. Dougherty, President of Dougherty & Associates, Prairie Village, Kansas.

#### **Dr. Jerome Wiesner Named to Automatix Board of Directors**

Philippe Villers, President of

Automatix, Inc., recently announced the election of Dr. Jerome B. Wiesner to the Board of Directors of Automatix. Dr. Wiesner is an Institute Professor and President Emeritus of MIT and a former Presidential Science Advisor. This action increases the size of the Automatix board from six to seven members.

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## *Calendar*

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**Introduction to Industrial Robots** is a seminar offered by the American Institute of Industrial Engineers, which will be held on March 21, 1981 in Merrillville, IN. The seminar is sponsored by the Calumet Chapter of the AIIE. For further information, contact Larry Ice or Linda Propsom, Indiana General Magnet Products, 405 Elm St., Valparaiso, IN 46383. (219)462-3131.

**Increasing Material Handling Productivity**, a three-day seminar dealing with conveyor alternatives, facility layout, storage systems, robotics and automatic guided vehicles, will be presented on opposite sides of the continent early in 1981 under joint sponsorship of the American Institute of Industrial Engineers and the Material Handling Institute.

The West Coast version will be conducted at the Kona Kai Club in San Diego, CA, Feb. 2-4, and the East Coast offering is scheduled March 2-4 at the Hyatt House in Winston-Salem, NC.

Registration information is available from: Conference Dept., AIIE, 25 Technology Park/Atlanta, Norcross, GA 30092.

**Automan '81, the First European Automated Manufacturing Exhibition & Conference**, May 18-21, 1981, Brighton, UK. Automan incorporates the 2nd Intl. Conf. on Assembly Automation and the 4th Annual British Robot Association (BRA) Conference. This event will address both the economic and technical issues

concerning the application of industrial robots. For details, contact: AUTOMAN '81, IFS (Conferences) Ltd., 35-39 High Street, Kempston, Bedford MK42 7BT, England.

**National Computer Conference, 1981**, Chicago, May 5-7. Interest is mounting for a panel to discuss Personal Robotics and Artificial Intelligence at the Personal Computing Festival of NCC '81. Those interested in participating should contact: A. Gelles, 185 W. Houston St., NY, NY 10014.

**International Conference on Computers and the Humanities**, May 17-20, 1981. U. Michigan, Ann Arbor. Contact: Richard W. Bailey, Chairman ICCH/5 Program Comm., Dept of English, U. Michigan, Ann Arbor, MI 48109.

**International Conference of Data Bases in the Humanities and Social Sciences**, May 20-23, 1981. U. Michigan, Ann Arbor. Contact: Gregory A. Marks, Chairman, ICDBHSS/3 Program Committee, Institute for Social Research, U. Michigan, Ann Arbor, MI 48109.

#### *Previously Announced:*

*Refer to the original Robotics Age Calendar announcement for details*

**RoViSec, the First International Conference on Robot Vision and Sensory Controls**, April 1-3, 1981, Stratford-upon-Avon, UK. Announced in Vol. 2, No. 3.

**7th International Joint Conference on Artificial Intelligence**, August 24-28, 1981 Vancouver, BC, Canada. Announced in Vol. 2, No. 3.

**IEEE Computer Society Conf. on Pattern Recognition and Image Processing**, Aug. 3-5, 1981, Dallas, TX. Announced in Vol. 2, No. 3.

#### **SME Clinics**

Robots: Management Overview Clinic, Houston, TX, Feb. 3-5, 1981; Oakland, CA, Feb. 24-26; Cleveland, OH, June 2-4, 1981; Denver, CO, June 16-18, 1981. Contact: SME, 1 SME Drive, PO Box 930, Dearborn, MI 48128, (313)271-1500.

# TECHNICAL ABSTRACTS

*As a part of our goal of disseminating current technical information to our readers, this department will list abstracts of significant recent technical papers, in cases where these papers are available to the public. The relevant addresses will normally be listed after the abstracts. We urge academic and industrial research centers to send us abstracts of recent papers in Robotics and Artificial Intelligence for possible inclusion in this department, with appropriate prices and ordering procedures.*

**Basic Research in Artificial Intelligence and Foundations of Programming**, by John McCarthy, Thomas Binford, David Luckham, Zohar Manna, Richard Weyhrauch, (STAN-CS-80-808)

Recent research results are reviewed in the areas of formal reasoning, mathematical theory of computation, program verification, and image understanding. (75 pp., \$3.95)

**An Extension of Screw Theory and its Application to the Automation of Industrial Assemblies**, by Jorgan S. Ohwovoriole, (STAN-CS-80-809)

Interest in mathematical models that adequately predict what happens in the process of assembling industrial parts has heightened in recent times. This is a result of the desire to automate the assembly process. Up to this point there has not been much success in deriving adequate mathematical models of the assembly process.

This thesis is an attempt to develop mathematical models of

parts assembly. Assembly involves motion of bodies which generally contact each other during the process. Hence, we study the kinematics of the relative motion of contacting bodies.

Basic to the theory of assembly is the classical theory of screws which, however, required substantial extensions for this application. The thesis begins with a review of basic screw theory, including line geometry and reciprocal screw systems, and new and more general derivations of some of these screw systems. We then extend the screw theory by introducing such concepts as "repelling" and "contrary" screw pairs, and "total freedom."

Finally, we give a method of characterizing assemblies of industrial parts. Using the extended screw theory, we then analyze the "general peg-in-hole assembly" and subsequently give a mathematical description of this particular assembly. (186 pp., \$4.50)

**Knowledge Engineering: The Applied Side of Artificial Intelligence**, by Edward A. Feigenbaum (STAN-CS-80-812)

Expert System research is an emerging area of computer science that exploits the capabilities of computers for symbolic manipulation and inference to solve complex and difficult reasoning problems at the level of performance of human experts. The methods of this area are designed to acquire and represent both the formal and the informal knowledge that experts hold about the tasks of their discipline. Numerous applications to science, engineering, and medicine have been accomplished. Expert System projects represent applied artificial intelligence research,

though they also make salient numerous fundamental research issues in the acquisition, representation, and utilization of knowledge by computer programs. Knowledge engineering approaches promise significant cost savings in certain applications; intelligent computer-based aids for practitioners in fields whose knowledge is primarily nonmathematical; and the elucidation of the heuristic knowledge of experts—the largely private knowledge of practice. There are major problems of knowledge engineering including the shortage of adequate computer equipment, the shortage of trained specialists in applied artificial intelligence, the scientific base for adequate knowledge acquisition, and the lack of sustained funding. (14 pp., \$2.15)

**Obstacle Avoidance and Navigation in the Real World by a Seeing Robot Rover**, by Hans Peter Moravec (STAN-CS-80-813)

The Stanford AI lab cart is a card-table sized mobile robot controlled remotely through a radio link, and equipped with a TV camera and transmitter. A computer has been programmed to drive the cart through cluttered indoor and outdoor spaces, gaining its knowledge about the world entirely from images broadcast by the onboard TV system.

The cart determines the three dimensional location of objects around it, and its own motion among them, by noting their apparent relative shifts in successive images obtained from the moving TV camera. It maintains a model of the location of the ground, and registers objects it has seen as potential obstacles if they are sufficiently

above the surface, but not too high. It plans a path to a user-specified destination which avoids these obstructions. This plan is changed as the moving cart perceives new obstacles on its journey.

The system is moderately reliable, but very slow. The cart moves about one meter every ten to fifteen minutes, in lurches. After rolling a meter, it stops, takes some pictures and computes for a long time. Then it plans a new path, and executes a little of it, and pauses again.

The program has successfully driven the cart through several 20 meter indoor courses (each taking about five hours) complex enough to necessitate three or four avoiding swerves. A less successful outdoor run, in which the cart swerved around two obstacles but collided with a third, was also done. Harsh lighting (very bright surfaces next to very dark shadows) resulting in poor pictures, and movement of shadows during the cart's creeping progress, were major reasons for the poorer outdoor performance. These obstacle runs have been filmed (minus the very dull pauses). (Thesis, 174 pp., \$4.35)

**Two Papers on Medical Computing—(1) Medical Cybernetics: The Challenges of Clinical Computing, (2) Consultation Systems for Physicians: The Role of Artificial Intelligence Techniques, by Edward H. Shortliffe, M.D., Ph.D. (STAN-CS-80-815)**

This memo contains two papers that deal with medical computing. The first, written for a book on cybernetics and society, examines the range of medical computing systems, plus some of the logistical and human engineering challenges

limiting their utility or acceptance. It addressed five recurring themes that characterize the introduction of medical computing systems: 1) the need for the proposed application, 2) the system users, 3) the logistics of system introduction, 4) the required computational techniques, and 5) the required technological resources. In the context of these topics, suggestions are offered for long-range research and resource policies that are appropriate for assuring the development of practical clinical computing.

The second paper, presented at a meeting on artificial intelligence in May 1980, takes a more detailed look at the reasons that medical computing systems have had a limited impact on clinical medicine. When one examines the most common reasons for poor acceptance for such systems, the potential relevance of artificial intelligence techniques becomes evident. The paper proposes design criteria for clinical computing systems and demonstrates their relationship to current research in knowledge engineering. The MYCIN System is used to illustrate the ways in which one research group has responded to the design criteria cited. (56 pp., \$3.40)

**Automating the Study of Clinical Hypotheses on a Time-Oriented Data Base: The RX Project, by Robert L. Blum, M.D., (STAN-CS-79-816)**

The existence of large chronic disease data bases offers the possibility of studying hypothesis of major medical importance. An objective of the RX Project is to assist a clinical researcher with the tasks of experimental design and statistical analysis. A major

component of RX is a knowledge base of medicine and statistics, organized as a frame-based, taxonomic tree. RX determines confounding variables, study design, and analytic techniques. It then gathers data, analyzes it, and interprets results. The American Rheumatism Association Medical Information System is used. (12 pp., \$2.10)

**Computational Uses of the Manipulation of Formal Proofs, by Christopher Alan Goad (STAN-CS-80-819)**

Formal proofs can serve purposes other than the presentation of evidence. In particular, a formal proof of a proposition having the form, "for each  $x$  there is a  $y$  such that the relation  $R$  holds between  $x$  and  $y$ " provides, under the right conditions, a method for computing values of  $y$  from values of  $x$ .

This thesis concerns (1) computational uses of the additional information contained in proofs, and (2) efficient methods for the representation and transformation of proofs. And extended lambda-calculus is presented which allows compact expression of the computationally significant part of the information contained in proofs. (122 pp., \$5.60).

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The above reports may be ordered from:

Dept. of Computer Science  
Stanford University  
Stanford, CA 94305

Give the Stanford University reference #, the title and author. Reports requested on microfiche are free; hard copy will be invoiced for the prices shown.

# LETTERS

Gentlemen:

I am enclosing a clipping from the *Milwaukee Journal* (Sept. 14, 1980) which refers to a report to the House Ways and Means Committee on US-Japan trade.

Although I am quite concerned about the human dislocations that industrial robotics could create for many displaced employees, I also feel some enthusiasm over the possibility that Congress will ultimately accept the necessity to develop the robotic industries and reindustrialize the nation.

Compliments on a fine magazine—I am learning a lot from you! Thomas Tollefsen  
Milwaukee, WI

The report referred to, WMCP-96-68, entitled "US-Japan Trade Report" (5 Sep 80), was prepared by the US-Japan Trade Task Force of

the Ways and Means subcommittee on trade. In view of Mr. Tollefsen's comment that "Congress will ultimately accept the necessity to develop the robotics industries and reindustrialize the nation," readers should consider some of the major points made by the report. In the preface, for example, the report states:

It has become increasingly clear to us... that our trade problems result less and less from Japanese import barriers and more and more from domestic American structural problems of competitiveness and quality.

Many of the findings of the task force point to the extent that the US corporate tax structure has crippled industry by stifling innovation, and discouraging investment, and they go on to suggest remedies that remove some of the present

restraints. Similarly, in the context of overall tax reform, bills such as HR 6632, which extends tax credits to businesses for contributions to universities for R&D work in specified areas, should be considered as a means of increasing domestic R&D that will translate into productivity gains.

The task force concluded that

It may be that the most important action we can take to compete with Japan is outside the realm of government action, and lies strictly with improved management by American businessmen which can result in major improvements in the quality of production and the morale of workers.

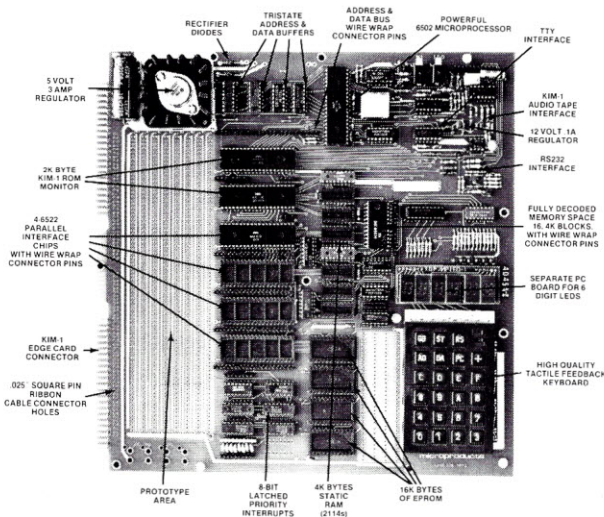
In outlining the possible options for dealing with the US-Japan trade imbalance, the report stated, "...we fear that because of the recession, a movement to restrict trade may develop in the Congress, ...and this is the option that we personally hope is not adopted."

**Robotics Age** supports these same conclusions in favor of market solutions to the problems of increased productivity and reindustrialization. In a favorable market environment, industry will respond to economic forces and restructure as needed. Ultimately, the responsibility for removing the obstacles to this responsiveness rests with the government and the people who elect it. —AMT

## Erratum

In our last issue, Fall 1980, the article "Superkim Meets Et-2" incorrectly named Microproducts, Inc. as the source of the Superkim computer. The correct source of this updated and enhanced version of the popular KIM-1 single board computer is Lamar Instruments, 2107 Artesia Blvd., Redondo Beach, Calif. 90278. (213)374-1673.

# SUPERKIM



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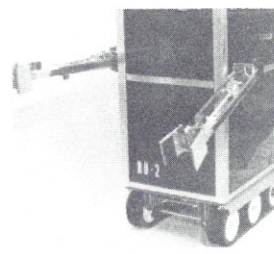
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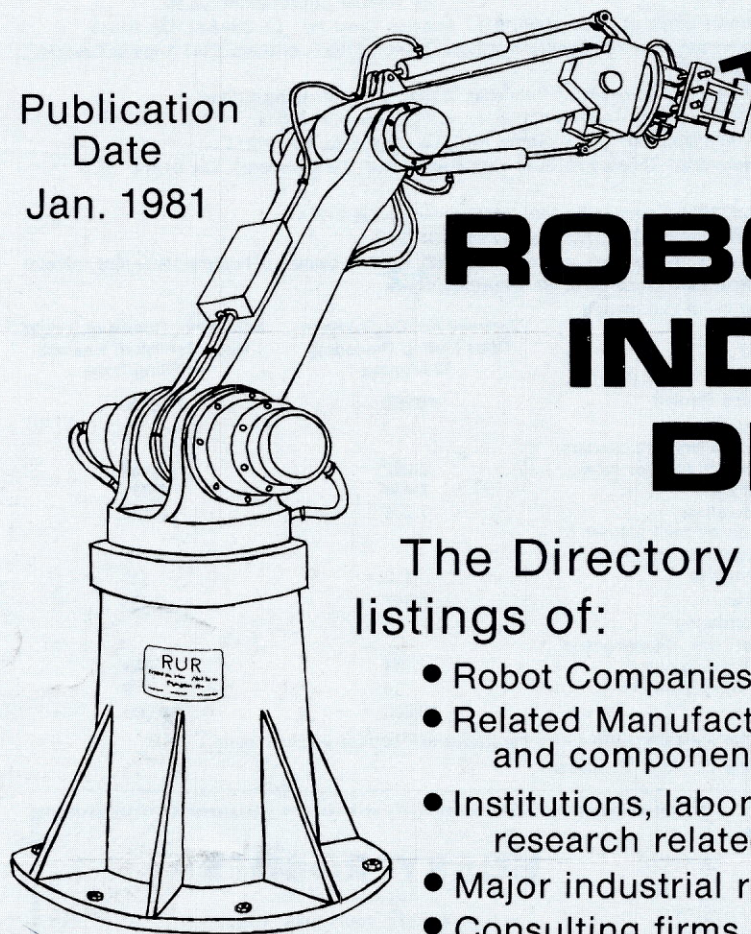
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